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Analysis of the combine header and design for the reduction of gathering loss in soybeans

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**Analysis of the combine header and
design for the reduction of gathering loss in soybeans**

by

Graeme Ross Quick

**A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY**

**Major Subjects: Agricultural Engineering
Mechanical Engineering**

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Signature was redacted for privacy.

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For the Graduate College

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Ames, Iowa**

1972

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LIST OF SYMBOLS AND ABBREVIATIONS

*	denotes statistical significance, at the 5% level ("significant")
**	denotes statistical significance at the 1% level ("highly significant")
\dot{x}	the first derivative of x with respect to time
\ddot{x}	the second derivative of x with respect to time
<u>x</u>	denotes vector quantity x
a	acceleration
ASAE	American Society of Agricultural Engineers
AOCV	Analysis of covariance
AOV	Analysis of variance
av.	average
Bul.	Bulletin
bu	bushel (U.S.). (1 U.S. bu = 1.03 Imp. bu.)
cm	centimeter
cpm	cycles per minute
dia.	diameter
diff. sig. at 10% level	difference is significant at the 10% level
ft	foot, feet
ft ²	square feet
ftm	feet per minute
fps	feet per second
G	gravitational constant (386 in./sec ²)
g	gram
HP	Horsepower

Hz	Hertz (1 Hz = 1 cycle per second)
in.	inch(es)
ISU	Iowa State University, Ames, Iowa
kg (=kg _f)	kilogram (weight or force)
kw	kilowatt
lab	laboratory
lb. (=lb _f)	pound (weight or force). ¹
NIAE	National Institute of Agricultural Engineers (U.K.)
n.s.d.	no significant difference
m	mass (lb. sec ² /in.)
MC	Moisture Content
mm	millimeter
mph	miles per hour
pto	power take-off
pps	pictures (or frames) per second framing rate
s	standard deviation
SG	Specific Gravity
SP	Self-Propelled
r	correlation coefficient
R ²	Coefficient of determination
rad	radian
rpm	revolutions per minute
USDA	United States (U.S.) Department of Agriculture

¹The Force-Length-Time system of dimensions is used consistently throughout this work. Other abbreviations, especially pertaining to mathematical expressions, will be defined as they occur.

1. INTRODUCTION

The modern combine harvester¹ is the most complicated and expensive piece of equipment used on most farms. It is probably also the least used.

In order to increase combine use and justify the expense of ownership, manufacturers have favored a universal design approach; they produce a standard model which will perform reasonably well, with only minor modifications, in a wide variety of crops and field conditions. The adaptation of the corn head as an attachment for the standard combine in 1954, for example, has increased combine harvested acreage in the U.S. over 20 percent (24).

The standard combine design is often found wanting when judged by one or more of the following criteria:

- (a) field capacity, or throughput
- (b) harvesting efficiency, or level of seed recovery
- (c) degree of damage to the seed
- (d) reliability.

Of these four, header throughput and recovery of seed (reduction of losses) will be dealt with in this work.

Combine losses fall into the two categories of gathering or header loss and through-combine losses. The through-combine losses (threshing,

¹The Australian expression "header" is descriptive of the same machine. Hereafter the more widely used term "combine" will be used for the grain harvesting machine, and "header" will be reserved for the gathering section of the combine.

separating and cleaning, and body leakage), have been markedly reduced by changes in design, the result of testing and laboratory studies over the past 20 years. The threshing and separating sections can be relatively easily tested indoors, once crop handling and storage facilities have been installed (50). A standard test procedure (25) and terminology (2) have been written for these components. The header mechanism, on the other hand, has been given comparatively little attention. Laboratory tests and a comprehensive analysis of the header have yet to be reported.

The header is the capacity-limiting component of the machine when harvesting soybeans. Header loss in this crop was reported to account for about 84 percent of all combine losses, which were in excess of 10 percent of the harvestable yield (8).

Illustrated in Figure 1 is a typical header design, consisting of a reel, reciprocating cutterbar with 3 in. guard spacing, and an auger platform.

Before the 1890's the soybean was hardly known in the Western world, although it was for centuries the oriental "meat of the field." Today, it plays an important role in world commodity trade. In an extremely short time it has risen to billion dollar status in U.S. exports. Total value of the U.S. crop was over \$2.5 billion in 1970 (72).

Because it provides the highest quantity of protein per acre of any field crop, the soybean is a candidate for a leading position in the nutrition of a burgeoning world population, both human and animal. Soybean yields have been rising consistently, from 11.0 bu/acre when the first combine was driven into a soybean field in 1924 by the Garwood

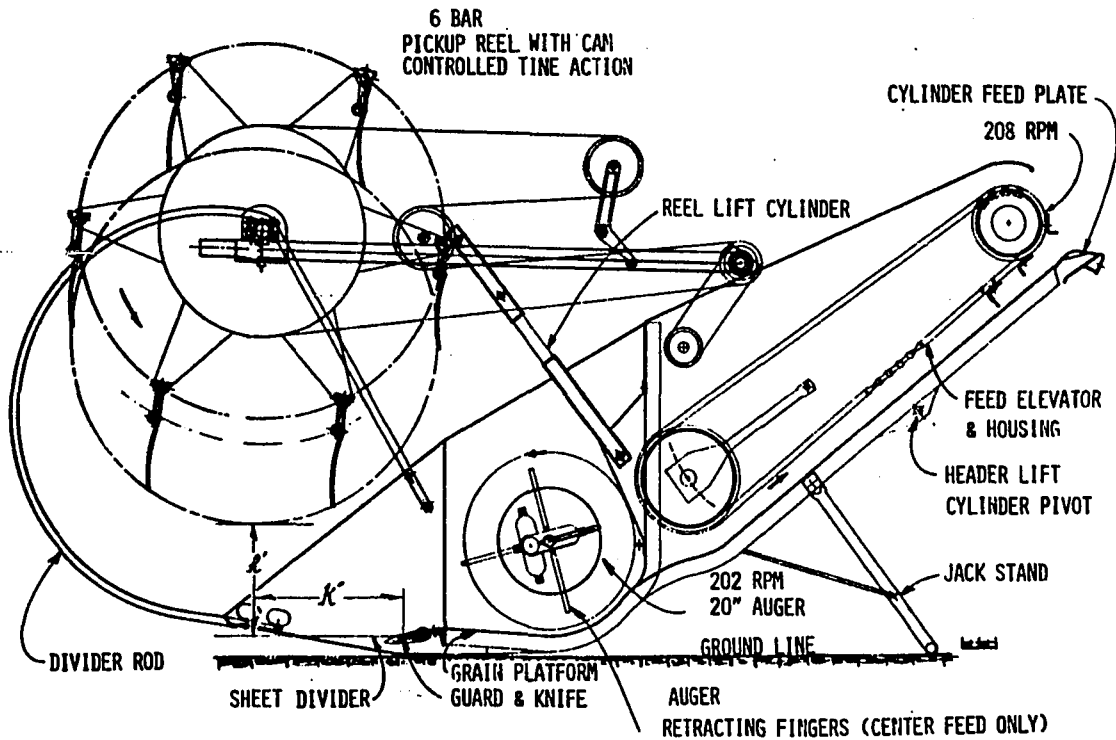


Figure 1. Semi-sectional elevation of a standard header, with pickup reel.

Brothers in Illinois, to a national average of 27.3 bu/acre in 1970. The combine made possible the initial upsurge in production of soybeans for seed; prior to this the crop had been grown primarily for forage and fertilizer.

The challenge of characterizing header performance and of improving it, the economic significance of reducing harvesting losses, and the growing importance of the soybean crop in a protein-poor world, were reasons which led to the selection of this thesis topic.

2. RESEARCH OBJECTIVES

1. To propose quantitative parameters for the evaluation of header performance characteristics in soybeans.
2. To analyze the mechanics of the standard combine header.
3. To study biological and mechanical aspects of the soybean crop pertaining to the problems of gathering loss and limited combine capacity.
4. To establish quantitative criteria by which the plant breeder may assess the combine-harvestability of new varieties.
5. To design and utilize a laboratory header testing facility and correlate its performance characteristics with those of the header operating in the field.
6. To ascertain and identify the precise nature and causes of header loss in soybeans.
7. To test the hypothesis that the cutting component of the header is the major contributor to header loss.
8. To propose, construct, and evaluate improvements in the header which will lead to a significant reduction in soybean loss and contribute to improved performance with higher header capacity.

3. REVIEW OF LITERATURE

"Seed time and harvest shall remain . . ."¹

The space age has brought dramatic changes, and has provided us a new perspective of our "spaceship Earth." From this vista the need for more judicious husbanding of the planet's finite resources is clear.

Seeds and grains constitute 67 percent of man's diet (77). To use these commodities as food for animals doomed for slaughter and to decrease thereby the effective food supply to one tenth of what it would have been by direct consumption needs to be more seriously challenged in this age of environmental awareness. Society can be enlightened to the nutritional advantages of the vegetarian diet.

The production of high quality protein foods for the growing world population will, in any event, increase the demand for seeds and grains. There will be a corresponding pressure for improvements in the machinery to harvest this food.

The combine evolved in the grain field, and in the U.S. became entrenched in the agricultural economy of the Pacific region for many decades before its first use for soybeans in the Midwest. Farmers in the "humid" central and eastern states were stationary threshermen by tradition, and often resisted the intrusion of this mobile contraption. Zealous Experiment Station Agricultural Engineers at first had to resort to bribery to coax farmers into testing the combine (26). Considerable inroads had been made by 1927, largely due to the need to harvest soybeans

¹Genesis 8:22 (King James version).

more efficiently than could the mower, binder, and thresher teams.

The design of a floating cutterbar was alluded to by Heitshu in 1928 (26). The same investigator suggested that the relative capacities of the various parts should be assigned as follows: cylinder 100%, cutterbar 75%, and separator 125-150%. The first patent on a pickup reel was filed in 1931 (68). The first recorded work on header height controls was published in 1949 (17), and in the '50s, following the decline in the use of the draper conveyor, the reel-auger-cutterbar header design had become universally established.

3.1 Historical Perspectives

Historical and Scriptural sources testify to an early art in the use of harvesting instruments for the acquisition of seeds and grains. Apparently this early art was much advanced over anything which was to be found during the Dark Ages (ca538-1798 AD).

The Gauls had a push reaper by 70 AD. Pliny wrote: "In the extensive fields in the lowlands of Gaul, vans (carts) of large size with projecting teeth on the edge, are driven on two wheels through the standing grain by an ox, yoked in a reverse position; in this manner the ears are torn off and fall into the van." Figure 2.

Palladius also wrote of this machine in the fourth century. A Belgian rock engraving uncovered in 1958 has revealed details of a Roman one-ass push stripper, the important first step in harvest mechanization.¹

¹Higgins, F. Hal. University of California Library, Davis, California. Combine history search at the F. Hal Higgins Library of Agricultural Technology. Private communication. Aug. 5, 1968.

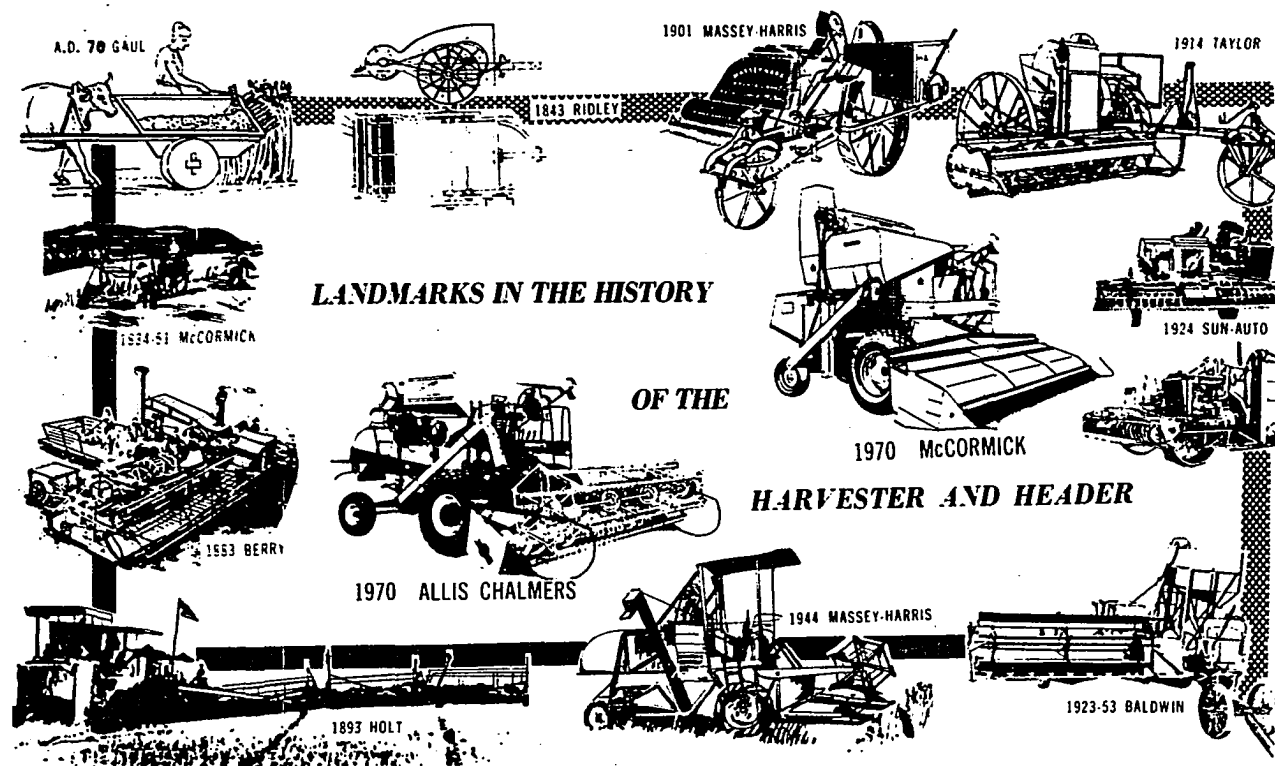


Figure 2. Landmarks in the history of the harvester and header.

The Royal Society of Arts, Manufacturers and Commerce published a description in 1783 of the "Pliny Reaper," and offered a reward for an improved model. It is believed that this event sparked the design of the reciprocating cutterbar and the gathering reel found in the reapers of the early 1800's (56).

Patrick Bell in England (1826), the McCormicks (1816-1850's) and Hiram Moore (1838) in the U.S. developed and used cutting reapers (56, 51). Shortly thereafter (1842) Australian inventors initiated the development of the "header-stripper" for standing cereal crops (81). Principal innovations in header design proceeded apace, yet independently, for almost a century on the two continents of the new world, before there began a convergence into the present form of the combine. In Figure 2, the Australian developments are illustrated on the upper side, proceeding clockwise, while the U.S. machines start on the left and proceed counter-clockwise.

The American horse-drawn machines probably evolved out of Cyrus Hall McCormick's 1831 reaper. They employed a cutterbar reciprocating through guards, conveying canvas and the bat reel. The first successful Australian machine, John Ridley's, used a stripping comb over which revolved a set of beaters to knock off, thresh the heads and deliver them to a box. There was no knife and the full straw was left standing (81).

A 22-ft wide platform, side-fed harvester, with a steam engine replacing the horse team, was probably the first self-propelling combine. This was built by Wm. Berry in California in 1887 and was capable of harvesting 50 acres of wheat in a day. By 1893, Benjamin Holt had built

and operated a 50-ft cut combine in California (51). Daniel Best of San Leandro was credited with having built the first combine which replaced ground wheel drive power with an auxiliary steam engine drive (11). The need for traction and flotation for these enormous combine harvesters led to the development of the first successful crawler track. Best and Holt later merged their interests to form the Caterpillar Tractor Company in 1925.

On the other side of the Pacific, by 1884, Hugh Victor McKay had added a winnower-cleaning section to the basic Ridley-type stripper, and in 1909 McKay had built a 24-ft self-propelled stripper-harvester with internal combustion engine side-mounted on the chassis (42). McKay's "Sunshine" factory was finding a large market for stripper-harvesters and, between 1895 and WW I, had even exported 10,000 machines. Such an export volume from the antipodes was bound to galvanize action from the North American harvester manufacturers, and one result was that Massey-Harris of Toronto went into production of stripper-harvesters (1901), followed by International Harvester Co. of Chicago in 1904. Neither company sold these machines on their domestic markets (4).

The stripper-harvester revolutionized the harvest operation by combining the gathering and threshing operations into one machine, but the stripper-beater with its knifeless long tooth comb had severe limitations in wet or down and tangled crops. Grain loss was also high in sparse crops. The challenge to produce a machine in Australia which could cope with these conditions was partially met by some farmers in New South Wales. They worked with Massey-Harris representatives, and adopted the knife into

their "reaper-thresher" (81). By 1910 the Canadian firm was manufacturing this long tooth combed machine specifically for export to Australia. It was another New South Welshman, Headlie S. Taylor, who finally overcame the problem of harvest lodging with the long-toothed comb, after several years of development on his header-harvester. He installed augers over the comb. This development attracted the interest of machinery manufacturer, H. V. McKay, who became impressed with its possibilities. McKay bought the manufacturing rights and then employed Taylor to work at the Sunshine factory in Victoria. In 1920, after a wet season in the Eastern Australian wheatbelt, the Sunshine header had won a wide reputation. Reasons for the success of the twin-auger header over the stripper-harvester were (81):

- (1) The front auger spiral (usually fluted on the periphery) rapidly removed the grain heads from the comb front.
- (2) The header cut off the heads instead of beating them off.
- (3) The crop mat was conveyed positively to the feed elevator between front and rear augers, on the "apron."
- (4) The "front" was always maintained level at any cutting height by means of a parallel linkage on the comb lift system.
- (5) The machine incorporated the winnowing fan integrally on the thresher drum shaft.

In 1924, Taylor produced the first Sun Auto-Header, a 12-ft self-propelled combine "with a comb front forming the widest part of the machine." The Tee-shaped combine configuration had arrived! This concept was patented and no other make of self-propelled combine with full-width

header was commercially released until the patent expired 17 years later. In 1938 a Sun Auto-Header harvested 3,300 bu of wheat in one day - a record that was unsurpassed during the next 33 years.

Elmer J. Baker, "the Reflector," of Farm Implement News fame (later Implement and Tractor Magazine), was to be instrumental in directing the Massey-Harris Company to deliver a combine for soybean harvesting to a subscriber in Illinois. The subscriber was an International Harvester dealer who was disgruntled because his company refused to ship him a combine for sale to the Garwood Brothers - clients who were growing soybeans near Stonington, Illinois. There is no record of a combine having been tested in any crop in Illinois to that date, 1924. The Reflector referred his reader to Massey-Harris at Toronto, with full knowledge that they had no sales facilities in the U.S. What followed is history. In the Nov. 20, 1924 issue of the F.I.N. the Reflector wrote:

The adaptation of the combined harvester to soy beans may open up a market of profitable proportions. . . . Heretofore there has been no machinery that harvested soy beans for seed to the satisfaction of the growers With the harvester-thresher it has been shown possible to cut and thresh the beans in one operation with minimum shattering and at low cost. The price received for soy bean seed is sufficient to justify the large grower to purchase a machine as expensive even as a combine. (4)

The success of the combine in the Illinois soybeans was followed by intensive breeding trials for the Garwood farms. The increase in plant size and yield led to a preference for the wide cylinder type combine. Several other harvesters were developed concomitantly for soybeans, but none could even closely approach the efficiency of the combine header (71). No other method succeeded as well. The American self-propelled and

pull-type combines of this era continued to use the draper-conveyor and side feeding.

The "straight-through" or "scoop" design, with full width threshing cylinder, made its appearance around 1935 and in 1938 Massey-Harris released the first self-propelled version, the "Clipper" (40). In 1939, coincident with the expiration of Taylor's patent, Massey-Harris offered the Model 21 combine of Tee-configuration (51). This machine was the outcome of the efforts of world-traveling Australian Tom Carroll to convince the company to build such a machine to meet the competition of McKay's Auto-Header. Carroll had been impressed with the performance of the Auto-Header in the Argentine where he was a Massey-Harris dealer. Returning to Canada in 1937, he persuaded the company to build the center-feed draper-conveyor combine.

The Model 21 Massey-Harris illustrated in Figure 2 was one of the famous "Harvest Brigade." The company was granted a special allocation of scarce steel to build 500 combines as an aid to the war effort. In 1944 these combines swept across one million acres in 10 States to harvest 25 million bushels of grain. One third of a million man-hours were saved, and for many farmers this was their first experience with the harvesting potential of this new type of machine (40).

Possibly the first U.S. combine to employ the auger was Curtis Baldwin's "Gleaner." Baldwin's earliest machines anticipated the "Uni-System" approach to farm machinery design, whereby the same power system is used for a variety of field machines. Baldwin mounted his machine on a Fordson tractor in 1923. His concept of mounting the threshing-cylinder

on the header still lingers in the modern "down-front" Allis-Chalmers combines. All U.S. combines now utilize the auger conveyor for header cross-feeding. Exemplary of the convergent trend to standardize header design is the fact that Australian "Headers," while being offered as standard models with the long-tooth comb or "closed-front" header, are also available with the short-tooth comb and reel "open-front" option.

Combine sales did not significantly increase until WW II when wartime shortages of manpower and grain spotlighted the need for more efficient harvesting. Today an estimated three million combines are in use throughout the world.

The present day version is more versatile than ever - the same machine can harvest a 5000-fold range of seed sizes - but it is also more complicated, containing an estimated 35,000 parts in one machine. It is more efficient, but it is also more expensive than ever. Purchase price has soared 70 percent in the past decade, without a proportionate increase in capacity.

3.2 Header Performance in Cereal Grains

Czukas (15) distinguished six possible crop orientations for feeding cereal plants into the threshing cylinder, and showed that smoother crop feeding can increase output, improve grain separation and reduce grain losses without increasing power. He suggested that

- (1) Suitable design of the cutterbar and operation of the reel could ensure that the crop (wheat) was favorably oriented. Ideal orientation was grain heads first and under the straw.
- (2) The crop material could be fed to the cylinder in bunches if the

cross-conveying auger speed was not matched to the feeder conveyor (10 fps typically).

Uneven feeding from the header can thus influence all other functions of the combine.

Goss et al. conducted studies on the combine in California barley. Header loss ranged from one to five percent of total yield at optimum reel speed setting. The importance of using a variable speed reel drive was stressed and the results pointed up the superiority of the pickup reel over the plain bat reel (23).

A broad survey of 286 combines in cereals conducted throughout England and Wales revealed highest grain losses at the cutterbar (14). Most of the machines were less than three years old. Only one percent were utilized more than 250 hours per year. In all, 13 makes were observed, in sizes ranging from 8- to 14-ft cut. Header loss results are summarized in Tables 1 and 2.

Table 1. Average pre-harvest ("shedding") and header loss^a for 286 U.K. cereal combines surveyed in 1969 (14).

	Loss (lb/acre)			
	<u>Pre-harvest</u>		<u>Header</u>	
	<u>Av.</u>	<u>Range</u>	<u>Av.</u>	<u>Range</u>
Barley	8	0-99	84	0-986
Wheat	5	0-55	42	0-268

^aYields were not stated, but by deduction from stated work rates and approximate field capacities, these average losses are estimated to vary between 1.2 to 2% of total yield.

Table 2. Combine grain losses from 1969 and 1970 U.K. surveys compared.^a

	Losses (lb/acre)			
	Barley		Wheat	
	1969	1970	1969	1970
Header loss	84	86	42	56
Through-combine loss	51	27	38	26
Total combine loss	135	113	80	82

^aRutherford, I. Ministry of Agriculture, Fisheries and Food Liaison Unit, NIAE, Wrest Park, Silsoe, Bedford. Grain losses during combining. Private communication. Mar. 22, 1971.

3.3 "Open Vs Closed Fronts" in Cereals

Regarding the comparative performance of the Australian "closed front" and the "open front" header, Figure 2, the Victorian wheat harvester study of Brown and Vasey in 1967 is instructive (7). Of all losses recorded in the 120 machines investigated, header ("comb") loss was the highest single loss cause. Of this total, only three machines with the "U.S. design," or open front, were observed, but in each case header loss was higher with the open front.

Table 3. Average header (comb) loss in the wheat harvester survey in Victoria, Australia, 1967.^a

	Average comb loss, % of total yield
Closed front	1.3 _b
Open front	3.7 ^b

^aTests recorded in wheat, average yield 25-30 bu/acre; crop height 25 in.; stubble length 16 in.

^bDifference not significant at the 5% level; only 3 machines in the sample of open front machines.

The Australians have the following reasons for adhering to their closed-front design for dry free-standing crops:

- (1) Better "combing" of the crop, resulting in less straw intake, with correspondingly better performance of the threshing and cleaning sections.
- (2) Adjustable comb tooth-spacing enables a variety of free-standing low moisture crops to be handled efficiently.
- (3) Lower losses of cut heads and seeds than with the open-front design.

Where high moisture conditions are encountered, and in down, tangled and weedy crops, the more versatile open-front header design is preferred. The closed-front design would not be practicable for soybeans due to the risk of the comb digging into the ground and of jamming of the irregular-sized and rough stems between the comb teeth.

3.4 Header Performance in Some Other Crops

3.4.1 Rice:

Finlayson told the Ricegrowers' Association of Australia, in an address in New South Wales, that difficult harvesting conditions in 1968, heavy yields (up to 10,000 lb/acre) and adverse weather (causing lodging and tangling), had proved too tough for existing rice headers. Seventy-five field observations were made on all current (open-front) machines under varying conditions. Average losses, largely lodging, were from 450 lb/acre to 4,000 lb/acre. Headers variously equipped with extended platforms, twin knives, crop lifters, narrower fronts, or draper fronts, performed best (19).

Manufacturers designed and installed extended platforms and modified

heavy duty sickle drives, e.g. with 4 in. stroke on 3 in. guards (Deere) and 2-3/4 in. stroke on 2 in. guards (J. I. Case). These out-of-register rice cutterbars provide a "progressive" cutting action, spreading the shock loads more evenly over the cutting stroke, without serious detriment to the cutting performance at low forward speeds.

Further developments in breeding and fertilization practices are looked for to help alleviate the lodging problem in Australian rice production.

3.4.2 Sorghum:

Grain sorghum, which is more resistant to drought than corn, is an important cash crop in parts of the Great Plains of the U.S. Wealti et al. (79) studied harvesting techniques in South Dakota, and the results of direct combining with an open front header are summarized in Figure 3. "Cutterbar loss" referred to all loose grain in the sample area less the estimated pre-harvest loss, and was fairly constant at approximately two percent. "Reel loss" referred to all grain heads in the sample area, and increased from 2.3 percent at high moisture to 5.2 percent later in the season. Many stalks were broken, with the heads lying on the ground. Some of these could have been recovered by a special reel or other attachment.

Total header loss was higher in subsequent years due to greater lodging, and the open-front machine compared unfavorably with the same machine equipped with Hesston row-crop gathering units. The early-windrowing field-drying-direct combining sequence was even more effective in reducing losses, however, when storms were encountered at harvest.

Planting in 12 in. rows, as compared to 30 in. rows, was an effective way of significantly reducing gathering losses. The explanation for the very important loss reduction obtained with narrow rows lays in the fact that storm damaged and broken heads were supported by adjacent stalks and did not touch the ground. Pre-harvest yields were about equal for the two row spacings.

3.4.3 Small seeds:

Direct combining is preferred over the windrow-and-pickup method of harvesting in the small-seed producing areas of Southeastern U.S., according to Park and Webb (54). Where extremes of weather are encountered, and where harvesting is otherwise delayed, seed losses were higher in the standing crop than in a mown swath or windrow. Under these conditions the advantages of direct combining may not be realized. The typical effect of harvest date on seed production and losses is shown in Figure 4. Cutterbar loss was over 10 percent in the more readily shattered crops. Header loss was lowered by employing the tined pickup reel (54). The importance of cutting low (even below 1 in.) was shown by Bunnelle et al. (9). Small seeds and lentil producers in Washington and Oregon often employ the floating cutterbar as a pickup device for windrowed seed crops.

3.5 Soybeans and Combine Header Performance

Following the success of the combine in that first Illinois trial, the same engineers who were to advocate the use of the combine were also on the scene to assess its performance (15). Soybean harvesting tests have been conducted by investigators in a number of States since that time.

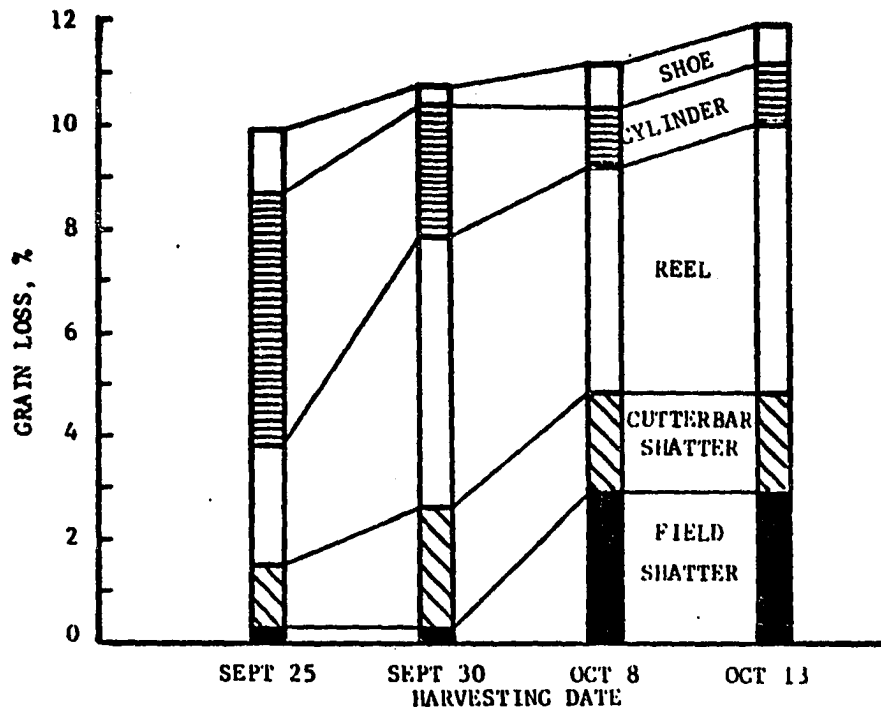


Figure 3. Effect of harvesting date on losses with the combine in grain sorghum in South Dakota (79).

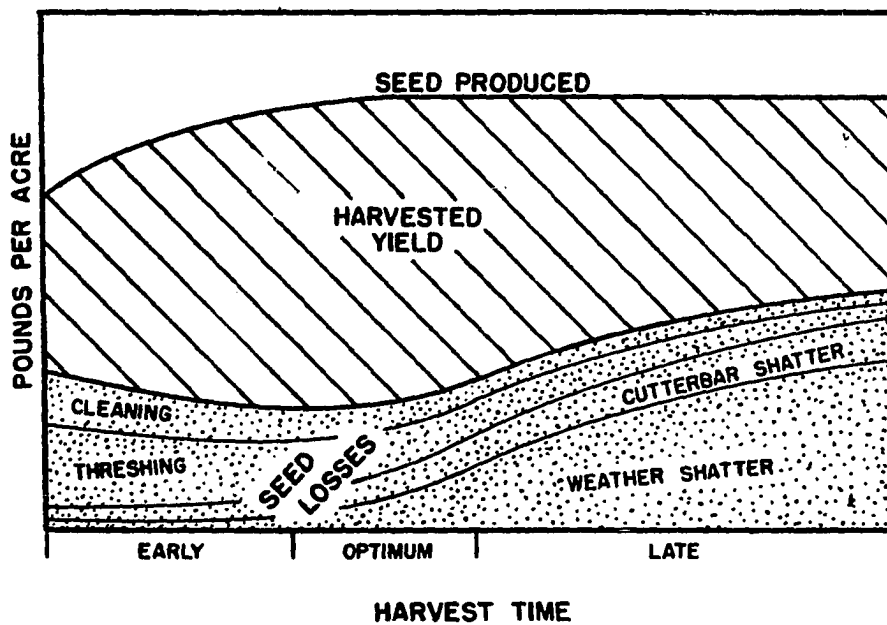


Figure 4. Effect of harvesting date on combining losses in small seeds (54).

The results of the tests have been summarized in Table 4.

Unfortunately, many of the authors failed to record pertinent details in their header loss studies. To report header loss in lb/acre, for example, is to supply partial information. In a crop such as soybeans, crop moisture and variety, cutting height and bin yield (or loss as percent of total yield) are essential data. There was also no unanimity in the definitions of the various losses.

Some of the results in Table 4 are plotted on the U.S. national average soybean yield chart, Figure 5.

It is unlikely that much credit can be given to combine designers for the steady increase in soybean yields. In fact, it might be concluded that the breeding of more shatter- and lodging-resistant varieties has probably been offset by the tendency of the operator to make fuller use of the increasing power of the combine, and thereby increase his losses by operating at higher forward speeds. As the forward speed increases, average stubble length increases; furthermore, header loss increases with header width (38).

3.6 Modified Headers and Attachments for Soybeans

Whatever other machines or schemes may have been used to harvest soybeans for seed, none approached the effectiveness of the combine. In 1939 Sjogren studied the mower-binder and the beater harvester (a machine built and used in the South ostensibly for the soybean crop) and compared their gathering performance with the combine. The average header loss with the other machines was typically twice as high as the combine's 12.4 percent average header loss (71). In 1949 Everett tested the first

Table 4. Soybean header loss investigations (standard headers only).

YEAR OF STUDY	INVESTIGATOR/S (REFERENCE)	STATE	MAGNITUDE OF HEADER LOSS AND RANGE	HEADER LOSS, AS PERCENT OF TOTAL LOSSES	COMMENTS
1925-1927	Lehman & Blauser [in Tate (75)]	Illinois	9.85% (5-21%)	88.4%	Draper conveyor side feed headers. 12 bu/acre yield.
1926	Wileman (82)	Indiana	6.4%	--	10' pto. Wet crop. Slow rate.
1927	Heitshu (26)	Virginia	11.10% (5.46-16.74%)	94.5%	3 draper conveyor headers.
1935	Hurst & Humphries [in Everett (17)]	Illinois	7.18%	78.2%	21 locations. 5 & 6 ft straight-throughs, 30 bu average yield.
1935	Hurst & Humphries [in Everett (17)]	Miss.	13.16%	79.4%	12 locations. 5 & 6 ft combines. 13.5 bu av. yield.
1949	Everett (17)	Iowa	15.13% (7.5-22%)	91.2%	Allis-Chalmers all-crop 2.5-3.5 mph. 33.1 bu average yield.
1956	Lamp et al. (38)	Ohio	7.0%	70.0%	29 machines. 28 bu 13.2% M.C.
1958	Park & Webb (55)	South Carolina	7.8%	80.4%	62 combines, good conditions, 20 bu av. yield.
1962	Lamp et al. (38)	Ohio	10.2% (6.8-15.2%)	87.3%	Various machines and varieties. 21-24 bu 10-18.5% M.C.
1965	Byg & Johnson(10)	Ohio	9.6% (3.0-7%)	93.0%	22 S-P machines.
1966	Hunt & Harper(31)	Illinois	4.61%	73.3%	12' J.D. S-P Var.Shelby 40 bu, 11-15% M.C.
1968	Nave et al. (49)	Illinois	6.18% (5.13-7.24%)	92.3%	13' J.D. S-P. 3 mph. 50.4 bu av., 4" nom.ht.
1970	Huitink (30)	Iowa	8.35%	--	10' Case, 13% M.C. Amsoys. 40.5 bu, 2.5 & 4.0 mph.
1969-1970	Schertz (66)	Minnesota	7.2% (3.3-12.6%)	--	15 farmer operations.
1970	Tate (75)	Illinois	10.99% (7.68-13.79%)	92.0%	15' J.D. S-P, 2.7 mph. 3 var., 49.4 bu, 12% - 16.5% M.C., 3.82" ht.
GRAND AVERAGES			<u>8.983%</u> (3.0-22%)	<u>85.0%</u> (70.0-94.5%)	

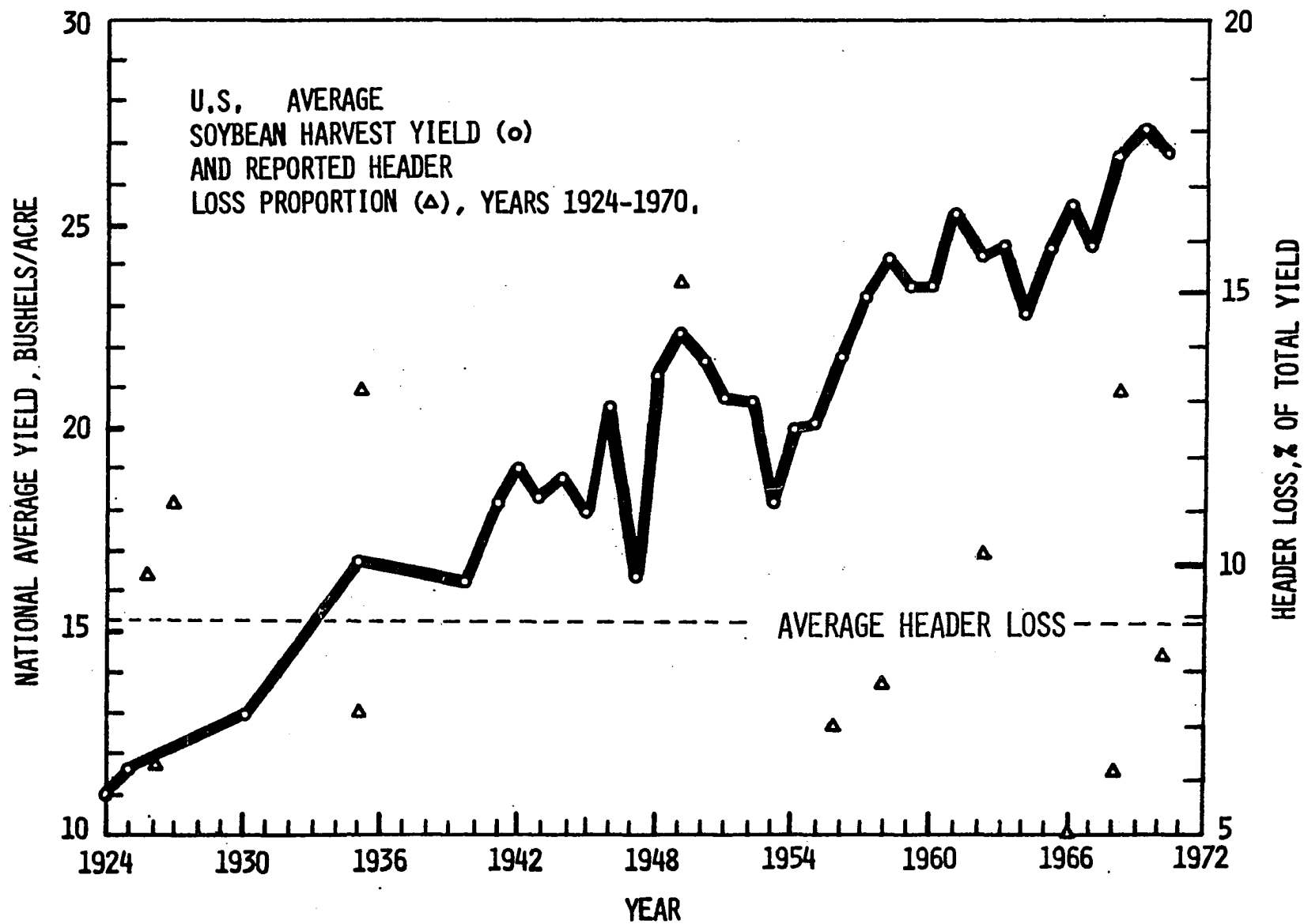


Figure 5. U.S. national average soybean yield (72) and header loss over the years 1924-1970.

reported automatic header height controller for soybeans (17). Performance with the hydraulic header height control was not as good as the same header with gage wheels, but he laid the ground work for the later development of the automatic header height control. Woodruff attempted to develop a fluidic control system behind the height sensor. The unit was unsuccessful because the fluidic system lacked the necessary speed of response (83). He also assessed the effectiveness of the Allis-Chalmers hydraulic height control by having the same operator drive the machine and endeavor to maintain the same cutting height with and without the height controller at varying speeds.

Table 5. Average stubble lengths (in.) for manual control and automatic hydraulic header height control (83).

	<u>Combine forward speed, mph</u>			
	2	3	4	5
Manual control	4.6	5.2	4.8	6.8
A-C hydraulic control	3.7	4.2	4.4	4.7

In reviewing the header height control art, Woodruff concluded that:

- (1) Manual control of header height for low cutting requires the operator's full attention, making it difficult to attend to the other machine functions and drive "on the row."
- (2) Manual control corrections tend to be larger than necessary.
- (3) Operation with an automatic height controller is less fatiguing.
- (4) Automatic header height control practically eliminates the chances of driving the cutterbar into the ground.

- (5) The higher stubble produced with manual control is largely caused by the operator raising the header to avoid nosediving.

Automatic header height controllers of several types are now available for attachment to all recent combine models, although only one combine manufacturer (Allis-Chalmers) offers the control as original equipment (3). Everett's gage wheel height control finds its modern counterpart in the John Deere spring supported header which floats on skids, but experience has shown that soil build-up on the skids under wet field conditions becomes a problem.

The pickup reel is now offered on all combine models sold for soybean harvesting and most have available on-the-go variable speed reel drives. An interesting array of row-crop and other header attachments are commercially available for the combine. A summary of some row-crop header attachments for soybeans is presented in Figure 6.

3.7 Summary

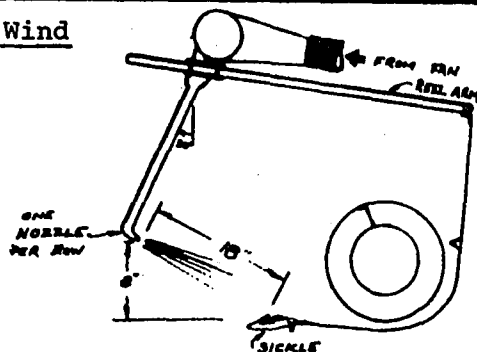
Header losses can be high in any crop harvested by the combine if the header is improperly adjusted and (or) carelessly operated. Where crop conditions are extreme or unfavorable, header and row-crop attachments are desirable and worth installing. In spite of the demonstrated advantages of some of these attachments, widespread acceptance, even of the floating cutterbar, is lacking. Only one combine manufacturer, Allis-Chalmers, builds an automatic header height control.

Header losses in soybeans have not markedly declined since 1927 and have averaged 8.98 percent of total yield.

This figure represents approximately 85 percent of all soybean losses,

(a) The Phillips Wind Reel:

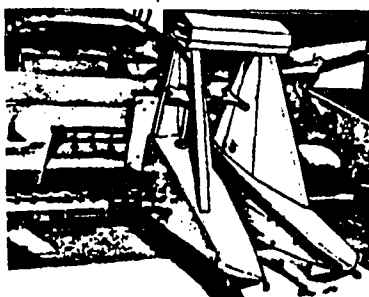
Park (53)
Phillips (57)



Significant yield increases obtained over conv. reels in small seeds. Successfully employed in cereals to reduce shatter. Also in soybeans, but no results reported.

(b) Hesston Row Harvester:

Mfd. by Hesston Mfg. Co.
Hesston, Kansas

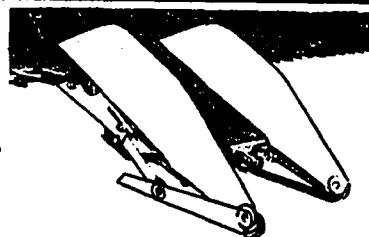


Header losses reduced by half in standing sorghum, 90 acres would pay for attachment. In severely lodged crop, break even as low as 16 acres Wealti et al. (79).

No tests in soybeans.

(c) Hesston Soybean Saver

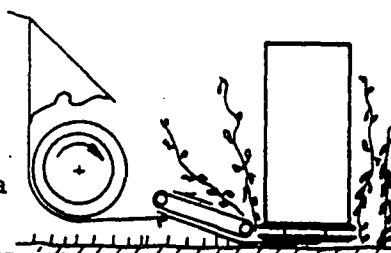
Mfd. by Hesston Mfg. Co.
Hesston, Kansas
"Bean Buckets"



Individual row floating cutterbar units. Loss reduction governed entirely by degree of reduction in stubble length.

(d) Rotary Cutter & Padded Roller Gathering Unit:

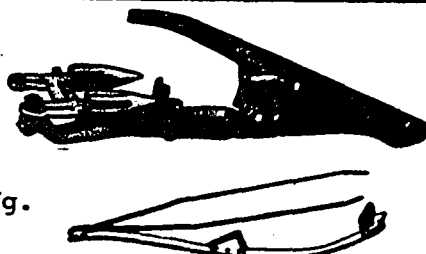
Schertz (66)
University of Minnesota
Experimental



Gathering losses approx. halved cf. std. header at 13% MC in 30" beans. [Losses expressed Bu/A only, yields not compared].

(e) Crop Lifters & Flexo Guards:*

*Mfd. by Richardson Mfg. Co., Cawker City, Ks.



Hinged pickup lifters are essential on rigid cutterbars in all severely lodged crops. Flexoguards for sorghum are more effective in standing than in lodged sorghum (79).

Figure 6. Some row-crop header attachments applicable to soybean harvesting.

and does not include pre-harvest loss (not chargeable to the combine). Through-combine losses are small, and are far overshadowed by header loss. Cylinder and cleaning losses can be held below 0.4 percent and may even be as low as 0.12 percent.

The trend toward narrow rows in soybeans and the lack of farmer acceptance of row-crop attachments would indicate that the best avenue for reduction of header losses would be a direct assault on the standard header. This would involve seeking the precise nature and causes of header losses in soybeans and attempts to develop improvements in the open-front header design which could be used in other crops as well.

4. THE SOYBEAN CROP

4.1 Soybean Production and Usage

The soybean, Glycine Max (L) Merrill, is an erect, bushy, leguminous annual with woody upright stem. Varieties grown in Iowa have a typical growing season of about 16 weeks. After a vegetative period of 6 to 8 weeks, depending on the photoperiodicity (onset of shorter days) of the variety, tiny purple or white flowers appear first around the fourth node then proliferate up and down the stem and branches. The fruiting pods appear in clusters and carry from 1 to 5 oblate or round seeds. A full grown specimen of the plant at maturity has shed its leaves and is a mass of pods ranged in tiers from stem tip to ground level. Heights range from 1 to 5 ft and there is usually some branching, Figure 7.

The introduction of the soybean, a native of the Orient, into the U.S. began in earnest around 1898, when W. J. Morse brought over more than 7,000 introductions to provide the germ plasm for subsequent breeding work (61). There are now over 300 named varieties and the germ plasm collection numbers 3,200 types, which serve as a base for the development of superior varieties (59). Selective breeding, improved production practices, the use of the combine and an ever-growing demand have resulted in a rapid increase in production of the crop.

Currently, soybeans hold third place in value of crop production and, in export trade, soybeans and their products are the highest U.S. dollar income earners. Over 75 percent of the world's crop is grown in the U.S. and a yet larger challenge lies before U.S. producers, as utilization has

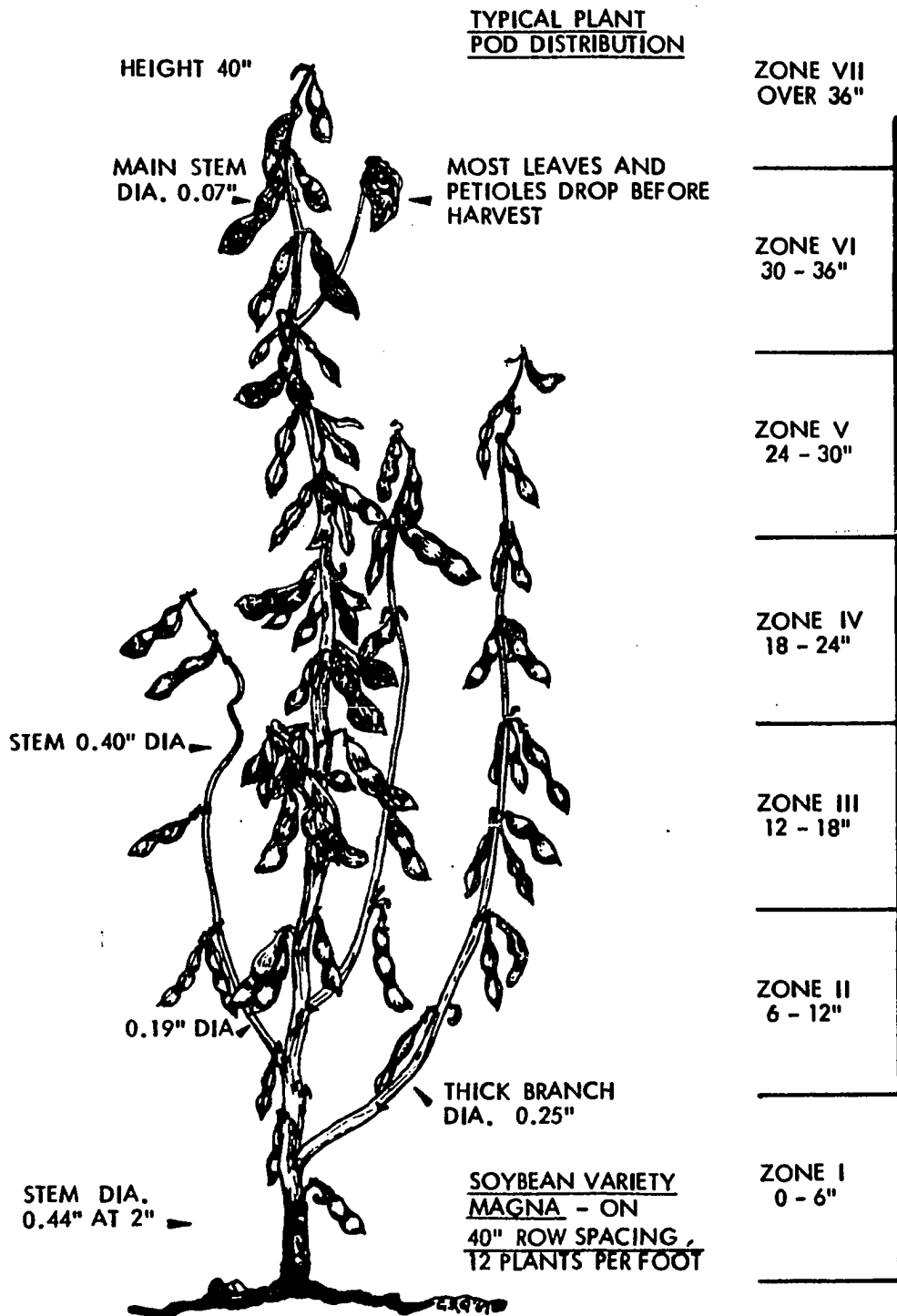


Figure 7. A typical soybean plant, podding zones delineated.

exceeded yield by 254 million bushels over the past two years, Figure 8.

In 1970, 42.4 million acres were harvested in the U.S. but the total disappearance was equivalent to almost 50 million acres (72). The seed carryover at Sept. 1, 1971 was estimated to be about equal to three weeks supply. This small carryover was insufficient to hold market prices at a stable level (46). The quick solution to this challenge is to increase soybean acreage, but the long term need is for improved production and harvesting methods. Yields have been increasing steadily but at a slower rate than for many other crops. The potential yield is over three times the current national average. The first 100 bu/acre yield came in 1968; a 2-acre plot in S. Carolina has produced 230 bushels and a number of farmers have consistently produced 60 bu/acre. Thus, today's varieties have the genetic potential to produce. Somehow, the crop that provides more edible protein per acre than any other must be more efficiently produced, harvested and utilized in this troubled world.

The soybean is easy to process. By-products can be reworked, modified and fabricated to create a vast range of products for human nutrition, animal agriculture and industry. Harry W. Miller MD, was one of the first to have the vision of feeding soybeans directly to protein starved people (47). Fifty years ago, as a Seventh-Day Adventist missionary to China, he used soybeans to save the lives of nutritionally deprived infants. Soyfoods have been the lifework of Dr. Miller. In Shanghai he set up one of the first modern soymilk plants in the world. Today we hear of CSM (a blended high protein flour combination), TVP (textured vegetable protein), soybean beverage powder, a spray-dried

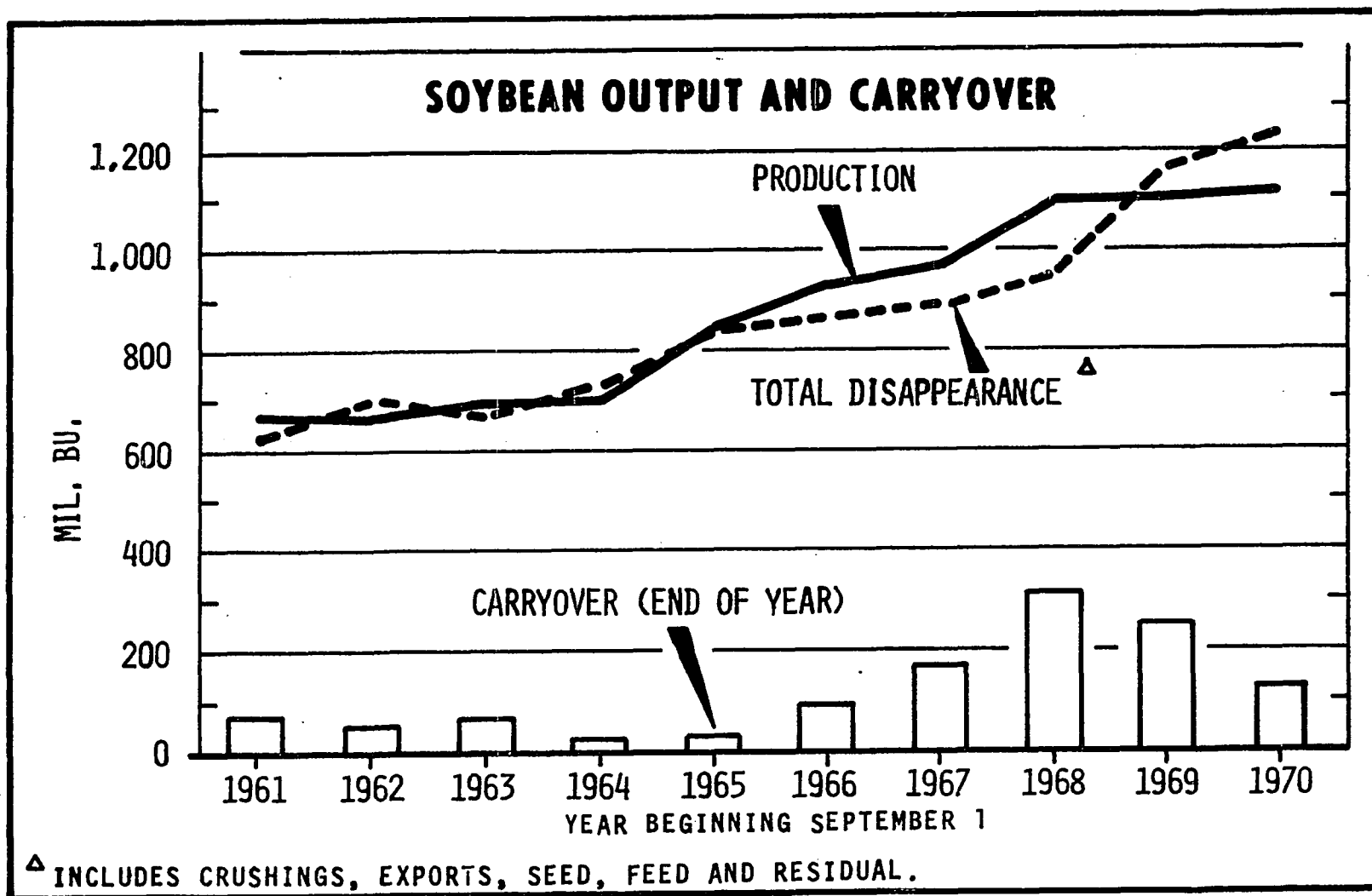


Figure 8. U.S. soybean production, usage and carryover 1961-1971 (72).

readily mixed milk substitute, and meat extenders (processed soybeans used with meat products to increase their protein quality and food value).

The use of soybean meal in feed rations for livestock has materially lowered livestock production costs. As population and spendable income increase in the richer countries, the demand for animal protein increases, in spite of the fact that soybeans produce the cheapest source of high quality protein of all processed human foods:

Table 6. Comparative costs of protein for human food.^a

Source	Protein cost per pound, dollars
Pork (retail)	6.47
Beef (retail)	5.85
Chicken (dressed)	1.75
Wheat flour	0.65
Peanut meal (defatted)	0.48
Dry skim milk	0.42
Cottonseed flour	0.21
Fish meal (feed)	0.18
Soy flour (food)	0.14

^aCompiled from several sources, and employing current 1971 U.S. retail commodity prices.

The industrial uses of soybeans extend from confections and paints to plastics and explosives, and the inventory is growing. The future demand for beans is such that an estimated 2,000 million bushels will be needed

by 1980. This increased need could be met by an increase of one million extra acres planted per year and an 0.7 bu/acre increase in annual yield (46). Soybean yields have been gaining only 0.6 million acres for each of the last four years. Without an increasing tempo in planting more acres the need to increase yield becomes even more critical. If harvesting efficiency was improved by reducing header loss to 3 percent, production would be increased by 6.6 percent, at present national levels of operation.

4.2 Economic Importance of Header Loss to the Farmer

Based on 1970 cost data for a 320 acre farm in North Central Iowa (29):

A 35 bu/acre bin yield would provide

A gross income of \$2.75/bu x 35 bu/acre, i.e.	\$ 96.25
Estimated production expense, from Howell (29)	<u>80.53</u>
Net income per acre	\$ 15.72

If the farmer's combining operation resulted in an overall loss of 10.7% of potential yield (38.9 bu/acre), and if 85% of this loss was header loss (i.e. 9% of potential yield), then:

Header loss represents

9% of 38.9 bu/acre x \$2.75/bu	\$ 9.63
Potential profit (100% harvesting efficiency)	\$ 26.57

Value of header loss as a fraction of potential profit is

\$9.63/\$26.57, i.e. 36% of potential profit.

Each percent reduction in combine loss is worth about one dollar per acre to this farmer.

An intelligent operator with a properly equipped machine could cut

losses to 3-1/2 percent in a good crop. This result has been verified on several occasions during the field trials enumerated in this dissertation. It might be observed, incidentally, that the farmer who is capable of consistently maintaining low combine losses would usually be capable of producing yields higher than 35 bu/acre.

4.2.1 Management for higher yields:

How do State and National champion soybean producers succeed? The following are key management factors for top production:

- (1) Selection of suitable varieties
- (2) Planting in narrow rows and exercising good judgment in selecting plant population
- (3) Timely harvesting and proper combine operation.

To the above must be added conscientious attention to the finer details of field preparation, fertilization, weed control, and the timing of these field operations. The three key management factors enumerated will now be studied in greater detail, as they relate to the combine header loss problem.

4.3 Selection of Suitable Varieties

It is important to select a variety adapted to the conditions in the field where it will be grown (67). In this research, four varieties with differing characteristics were grown over the years 1967-1971, Table 7. In 1971 the field plots were prepared as outlined in Table 8.

From the harvesting point of view the following varietal characteristics are critical:

Table 7. Typical varietal performance in Central Iowa - 1970.^a

Characteristic	Amsoy	Corsoy	Hawkeye	Hark
Yield, bu/acre 1968-1970	49.6	51.0	44.4	49.4
Maturity date ^b	Sept. 18	Sept. 18	Sept. 17	Sept. 13
Height, in.	42	40	40	37
Lodging score ^c	1.9	2.6	2.0	1.7
Seeds per pound	2600	2600	2500	2700
Special comments	Lower seed quality.	More lodging susceptible.	High seed quality. Low yield.	Earlier maturing. Shorter.

^aFehr, W. R. ISU Agronomy Department, Ames, Iowa. Soybean varietal performance. Private Communication. Aug. 5, 1971.

^bMaturity: Crop is considered mature at date when 95% of pods have ripened. Seven to ten days of good drying weather are required beyond this date before beans are ready to combine.

^cLodging: Scores range from 1.0 to 5.0, with 1.0 signifying all plants erect and 5.0 signifying all plants flat.

Table 8. Field preparation and timing for soybean production in plots at the ISU Agronomy-Agricultural Engineering Research Center, 7 miles west of Ames.

Variety	Amsoy, ISU certified seed stock
Planting date	May 12, 1971. Field 50
Planting rate	190,000 seeds/acre on 30 in. rows
Actual stand count	Av. 7.3 (range 4 to 11) plants per foot
Cultivation	Pre-plant disk & rotary cultivation following fall plowing
Herbicides	Amiben 2 lb./acre as liquid spray, following planting
Mechanical weed control	May 22, rotary hoe, following seedling emergence May 27, rotary hoe June 3, Lilliston rolling cultivator June 10 & 23, tine cultivator with sweeps. Plots trimmed & hand weeded for removal of sunflower, volunteer corn & cocklebur. Severe hailstorms in early July caused early lodging
Physiological maturity	About Sept. 17, slightly early due to dry seasonal conditions
First combine tests	Sept. 27, at 11% MC

4.3.1 Lodging resistance:

Varieties that stand well where lodging is known to be a problem may be the most profitable, even though they may have a slight yield disadvantage in variety trials. Profits depend on bushels harvested, not bushels grown. Lodging is associated with decreased seed yield and quality, both because of adverse physiological response and decreased

harvesting efficiency. Weber and Fehr conducted yield trials to study the effect of lodging on yield. The plots were harvested against and with the direction of lodging, and the yield difference between the two harvesting directions were assessed as lodging loss. By harvesting two varieties this way the average loss in yield was 1.3 percent. In adjacent plots where plants were staked to prevent lodging, average yield was 13 percent higher (80). Planting density and row spacing exert an influence on lodging propensity for a given variety (13).

4.3.2 Shatterability:

In the wild state, soybean pods dehisce as soon as they mature and disperse their seeds some distance from the parent plant (12). Natural dehiscence in modern commercial varieties is minimal and tends to occur slowly - the pod carpels open out, then slowly twist through approximately 450°, usually without projecting the seed.

The pod cell wall structure was studied by Monsi, the illustrations in Figure 9 being adapted from his original work (45). The cellular structure of the pod wall consists of several rows of thick-walled cells oriented at an angle to the long axis of the fruit and covered internally by a thin-walled epidermal layer. The two differentiable micelle layers of the endocarp, designated as the 'B' and 'W' layers by Monsi, were noted to have a mean difference in helical pitch orientation of 96°. As a result of this different orientation the layers undergo their strongest contraction in different planes, resulting in the carpels twisting after dehiscence. When the tension produced by alternate wetting and drying cycles or by a mechanical action becomes sufficient, the conspicuously

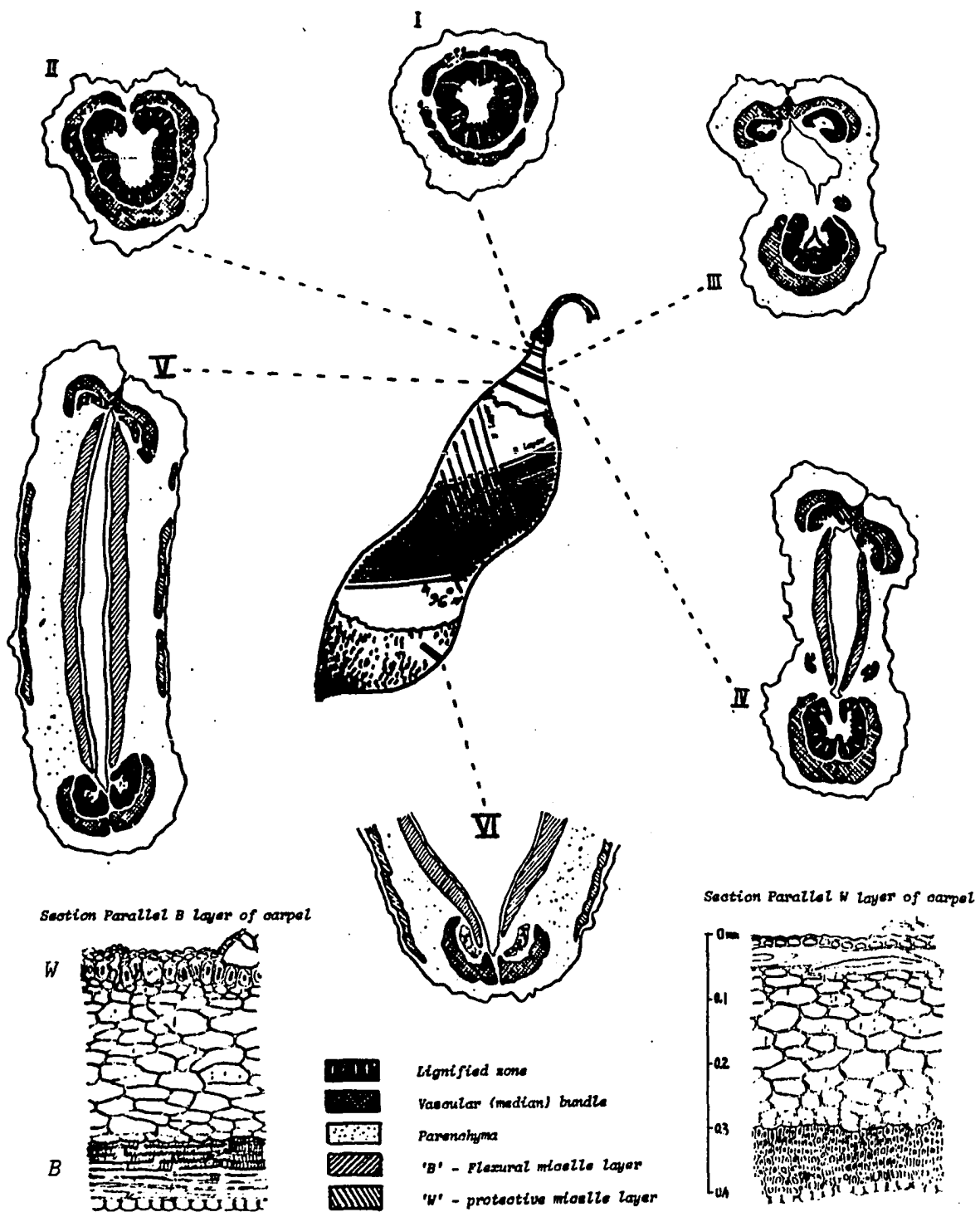


Figure 9. Soybean pod physiology.

thin-walled parenchyma cells part along one or both lines of dehiscence - one following the line of union of the carpel margin and the other in the fasciated median bundle, or suture. Usually the suture is the weaker and opens first to expose the seeds on the upward side. In the field, pods were occasionally seen that were partly open along the suture prior to harvesting.

Agronomists use a "shattering index" as a criterion for field estimation of the natural or pre-harvest shatter loss of a variety. According to this criterion, varieties are assigned a certain value between 1 and 5, depending on the relative number of pods which have dehisced at a specified time after physiological maturity. This index is not suitable for assessing the mechanical shattering propensities of a variety, since two varieties at the same level on the agronomic shatter scale have been found to have differing mechanical shattering resistance. An engineering shatter scale is proposed, in which a quantitative index, based on compressive force, for example, is assigned when initial pod failure occurs under a given moisture content and set of loading conditions. This is discussed later.

Caviness (12) studied the effect of relative humidity on pod dehiscence and found that a standardized experimental method of cyclic wetting and drying increased the rate of dehiscence at the higher humidity levels, but not to the magnitude expected from field observations. He suggested that other factors, such as sudden temperature changes and wind movement, may enhance the shattering rate, Figure 10.

4.3.3 Podding height and branching tendency:

Plant density, row spacing and weeds largely control the podding height and branching tendency, Figure 11. The soybean plant is remarkably versatile in its adaptability to production practices and weather conditions. It is aided in this by a comparatively long flowering period. If the seed planter should skip and leave a space, adjacent plants will subsequently react by sending out more branches and by setting more total pods per plant. The plant is also able to adjust when branches are removed as they appear. It does this by setting more pods per node and increasing seed size.

Branching is an undesirable characteristic with respect to combine harvesting. Low branches and pods near the base of the plant inevitably exist within the cutting zone of the combine and their presence contributes significantly to cutterbar loss, pod stripping and shatter.

An engineer's interpretation of the ideal variety of soybean, bred and cultivated to minimize field and header losses, is shown in Figure 12. If plant breeders could develop a productive variety with these attributes, the header loss problem would no longer exist.

4.4 Row Spacing and Plant Population

Traditionally, soybeans have been grown in 42 in. rows alongside 42 in. corn. This was the width of the singletree on the hitch of the draft animal used to cultivate the corn. The farmer used the same planter and cultivators for both crops. Varieties currently in use were bred and developed in 36 in. to 42 in. wide rows. In the Midwest, however, it has been found that soybeans grown in rows spaced closer than 40 in.

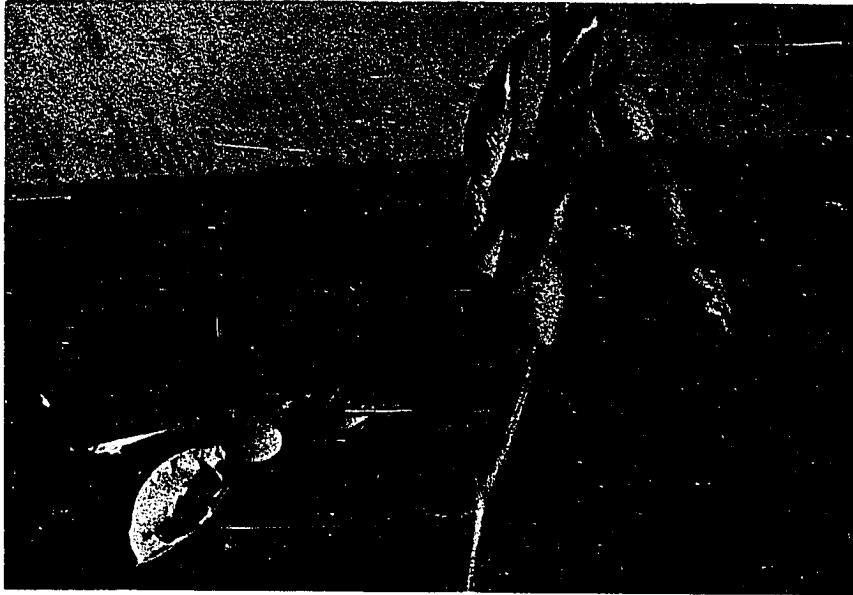


Figure 10. Natural pod dehiscence. Weather fluctuations after crop maturity are the major cause of pre-harvest losses.

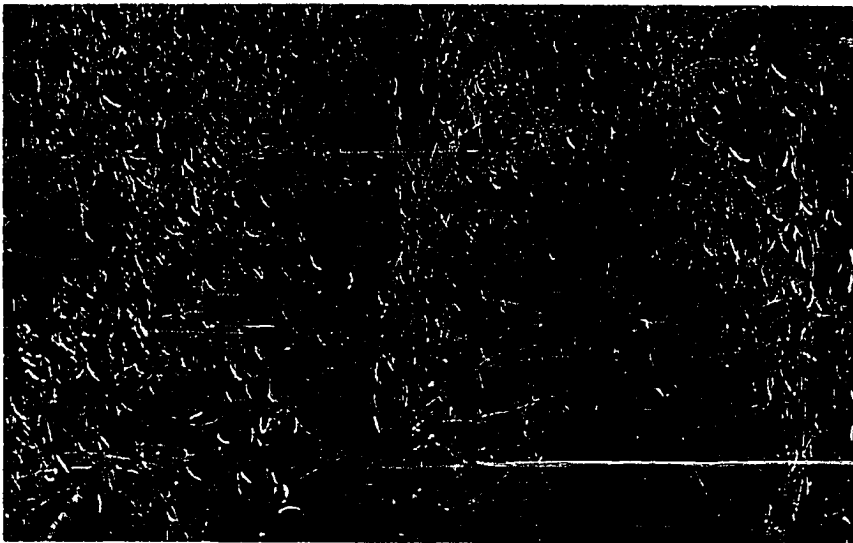


Figure 11. Low branches and lodged stems pose difficulties in the gathering of soybeans by the header.

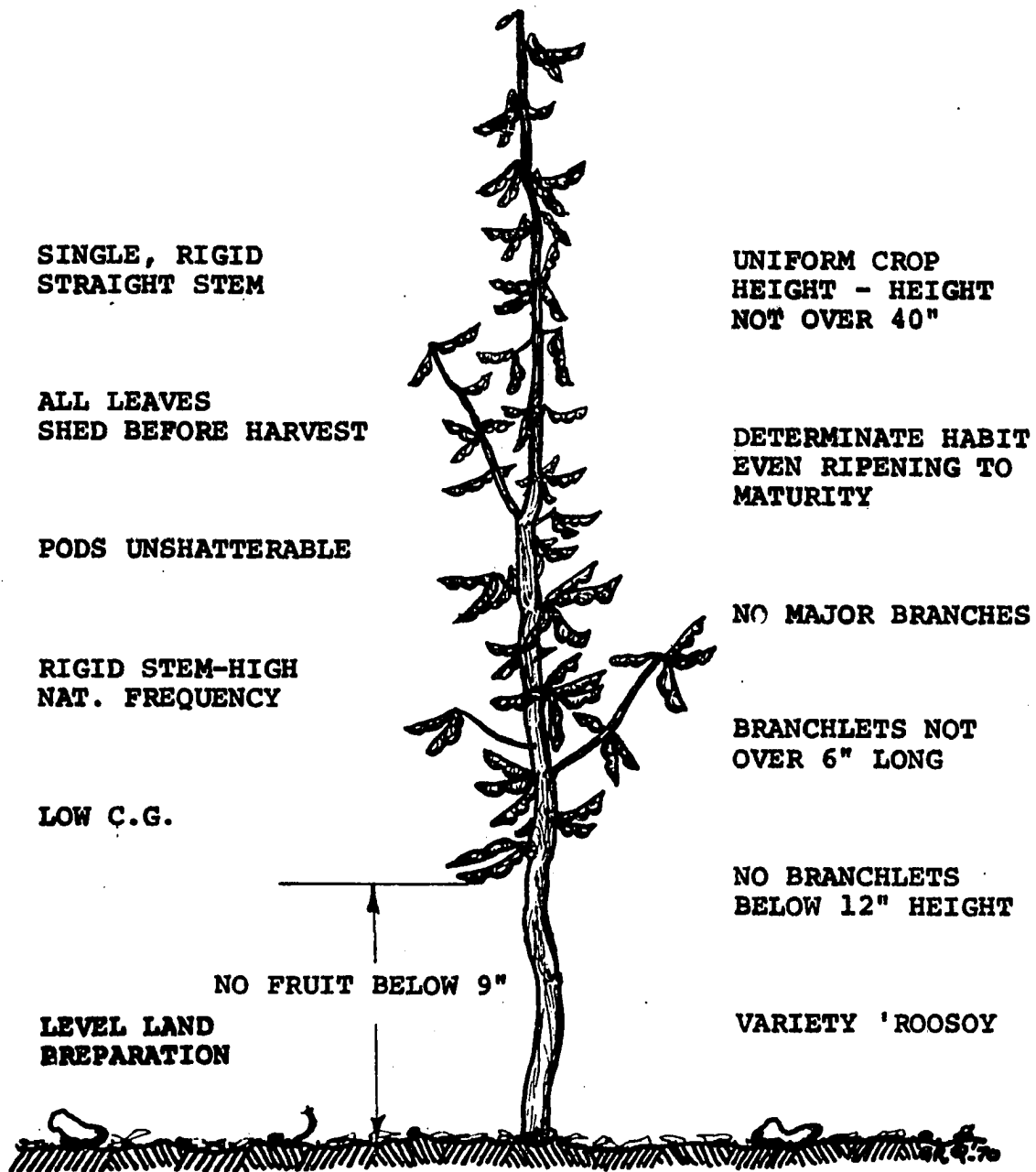


Figure 12. An engineered soybean plant, desirable from the harvesting point of view.

consistently outyielded those grown on the wide rows, provided adequate weed control was maintained. The availability of more effective herbicides and development of newer cultivating equipment has brought about a gradual trend toward narrow rows (any spacing less than 30 in. is called "narrow row" spacing).

Vastly different response to narrow rows has been reported between the northern and southern soybean regions of the North American Continent (48). The main reason for the different response between the latitude extremes lies in the types of soybeans grown.

In the South, determinate types of soybeans are grown, whereas in the Northern regions indeterminate types are grown. The relative yield advantage of narrow spacing is dependent upon the interception and utilization of light. The determinate plant has a longer vegetative period, produces more branches, and will make its full height before flowering. It is thus able to intercept most of the incident light before the reproductive period ends.

In the South, yield responses to narrow rows are rare. The Northern indeterminate types, on the other hand, may have only reached one quarter or one half of mature height before the onset of flowering. They cannot intercept all of the available light energy if widely spaced. Planting indeterminate types in narrow rows will generally result in higher yields because there is:

- (1) more efficient early interception of light energy,
- (2) reduced moisture loss from the soil, and
- (3) narrow rows permit higher plant population per acre with less

risk of a severe lodging problem.

Typical responses obtained with narrow rows in Iowa are shown in the following table from Thompson and Herman:

Table 9. Row spacing and plant population : effects upon soybean yields (76).

Plants per acre	Yield in bushels per acre from row spacing of:			Percentage yield increase over 40-in. rows from row spacing of:	
	10 in.	20 in.	40 in.	10 in.	20 in.
25,000	43	39	36	19	7
50,000	47	44	38	23	16
100,000 ^a	48	40	35	35	13
200,000	37	33	36	3	-7

^aPlants 1-1/2 in. apart in 40-in. rows give 100,000 plants per acre.

There is a certain price to pay in the switch to narrow rows. Different machinery may be needed, and the reduction in row spacing is usually effective only to the extent that weed control can be assured. Cooper points out that there is a tendency for some growers to overdo their planting rates in narrow rows (13). Overplanting results in more spindly plants, with increased risk of early lodging.

For a given environment, reducing row spacing (while maintaining the same plant population) results in shorter plants, less lodging, and correspondingly improved harvesting efficiency.

The planting patterns of some national champion soybean growers have included the following (13):

2.5 plants/ft in 7 in. rows,
 14.0 plants/ft in 28 in. rows and
 7.5 plants/ft in 30 in. rows.

4.4.1 Effect of row spacing on header loss:

A cooperative experiment was set up with USDA Agricultural Engineers to ascertain the effects of row spacing on harvest losses. The results are summarized in Table 10, and the procedural details of the experiment are covered in the next chapter.

Table 10. Summary of row-spacing/header loss study^a, harvested October 14, 1970 with a Case 960 13-ft combine. Variety Hark, 15.2% MC.

Row spacing in.	Final stand plants/acre	Row density plants/ft	Height of lowest pod in.	Total yield bu/acre	Header loss percent
10	179,970	3.43	3.05	48.73	4.59
20	131,639	5.02	2.88	46.34	5.89
30	123,057	7.05	2.93	40.64	5.88
Conclusions	**			**	**

^aConducted in collaboration with D. E. Wilkins, D. C. Erbach and W. G. Lovely, USDA, ARS, as a combined row spacing, crop residue, residual herbicide, and cultivation investigation.

**
 Denotes difference highly significant, i.e. at the 1% level of significance.

4.4.2 Summary - row spacing a most important factor:

Narrow rows make an important contribution to the reduction of header loss. Narrow row spacing in Iowa, with appropriate varieties, generally results in

- (1) higher yields
- (2) slightly higher podding
- (3) less branching
- (4) less lodging, when plant population is optimal
- (5) shorter plants
- (6) slightly smaller beans, in more pods
- (7) slightly higher production costs
- (8) earlier maturity.

If the current trend to narrow rows from 30 in. to as low as 7 in. (or broadcast) should continue, there would be no reason to consider "row crop headers" as anything more than a stop-gap measure, however efficacious they may be in wider rows.

4.5 Timeliness of Harvest

Timeliness of harvest has been shown to be a significant economic factor in the production of soybeans in Illinois. Hunt and Harper (31) have estimated the monetary penalty associated with untimely harvest. Their studies, shown in Figure 13, led to the conclusions that:

- (1) Timeliness was a significant factor in the economic harvesting of soybeans in Illinois.
- (2) There were only a couple of days when the monetary loss was at a minimum.
- (3) There were important differences among varieties in the amount of economic penalty associated with untimely harvest.
- (4) Timeliness factors ranged from 0.00113 to 0.00035, depending on variety. To determine the cost of harvesting delays, in dollars

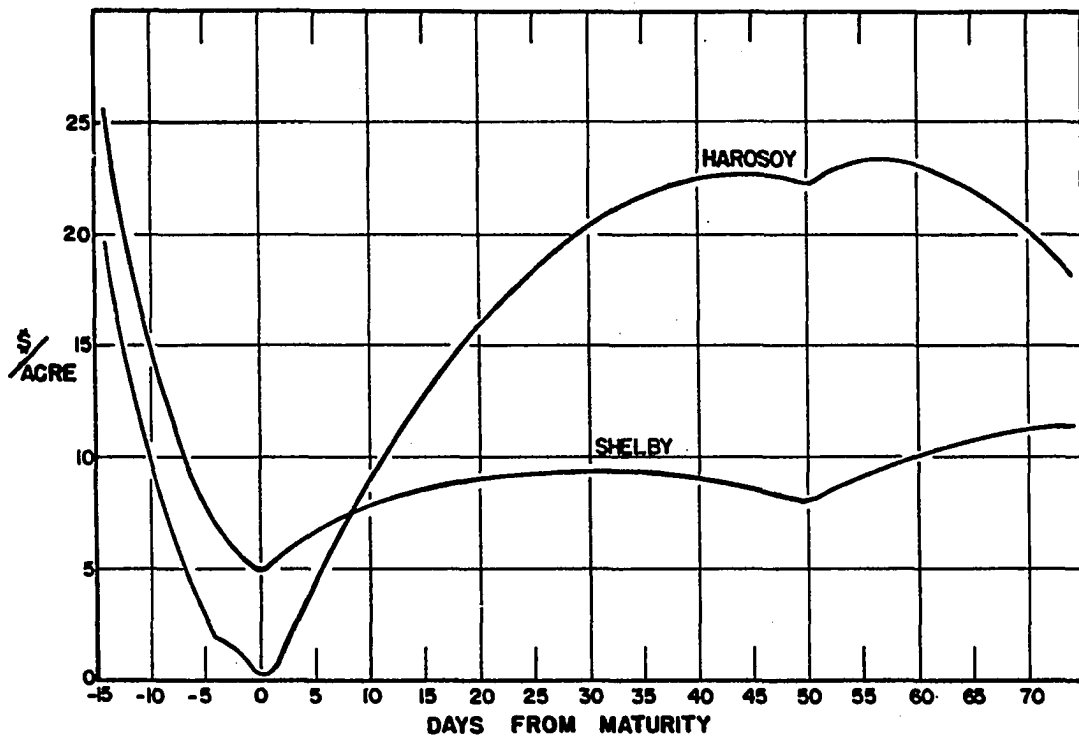


Figure 13. Monetary loss with time by variety (31).

per hour of machine operation, multiply the timeliness factor by the acreage, the yield in bu/acre and the value in dollars per bushel.

The maturity date referred to in Figure 13 should be distinguished from the Agronomists' "physiological maturity" date, as previously defined in Table 7. Hunt and Harper refer to the date when harvesting could begin, i.e. when seed moisture had first fallen to 13 percent, a date seven to ten days later than the agronomic maturity date.

Can the date of harvesting be advanced? If combining commenced before maturity, the higher moisture beans harvested could be artificially dried for storage. There is a marketing penalty on beans sold at higher than 13 percent MC. The principal advantage in advancing harvest date

would be to reduce shatter losses at the header.

To answer this question, drying rate studies, on a seasonal and diurnal basis, were undertaken. The seasonal rates of drying of seed of the three varieties - Amsoy, Hawkeye, and Corsoy - in 1969 are seen in Figure 14. The most striking feature of the graphs, which is common to each, is the precipitous onset of drying of the seed when plant senescence sets in. The most rapid drying rate was found to correspond fairly closely with the attainment of 100 percent leaf drop. The natural rate of drying was as high as 6 percent per day at this stage, and was little affected by weather conditions.

The stems and pods also displayed rapid drying rates but "out of phase" with the seed, Figure 15. In variety Amsoy, the pod moisture level lagged seed moisture level by one to two days, and the stems by five days, during their most rapid drying phase. Eventually moisture content of all parts of the plant "leveled off" and was then equally subject to diurnal weather variations. Day to day climactic conditions subsequently controlled the threshability of the soybean through the harvest season.

The diurnal fluctuations of moisture in the plant parts are seen in Figure 16. Pods absorbed most moisture during the cooler or more humid parts of the day and beans absorbed least, with stems intermediate.

Moisture levels in the pods and stems could fluctuate by as much as 5 percent during a measured, rain free, 24-hour period. This explains why plants are "tough to thresh" and have lower shatter losses when harvesting begins in the morning. Moisture cycles of all plant parts lagged humidity and temperature cycles by about 4-1/2 hours.

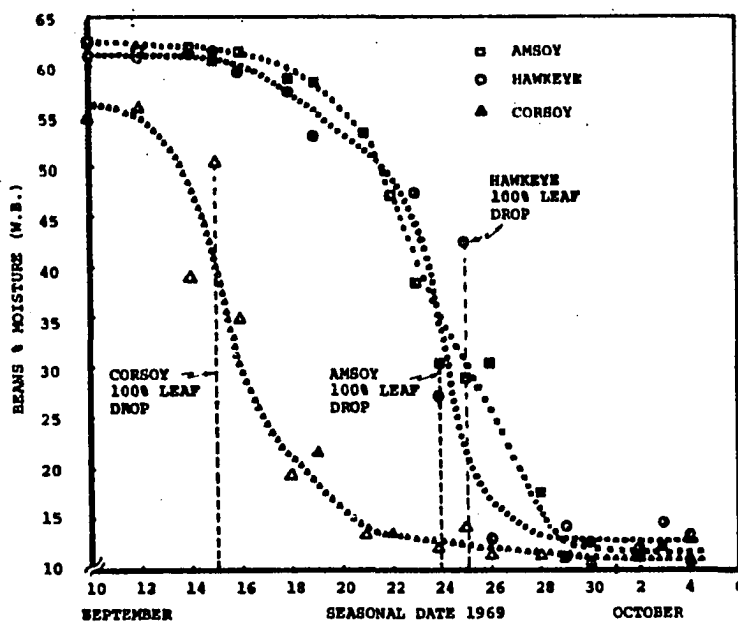


Figure 14. Natural drying rates during 1969 season for three soybean varieties. Moisture content measured in the seed.

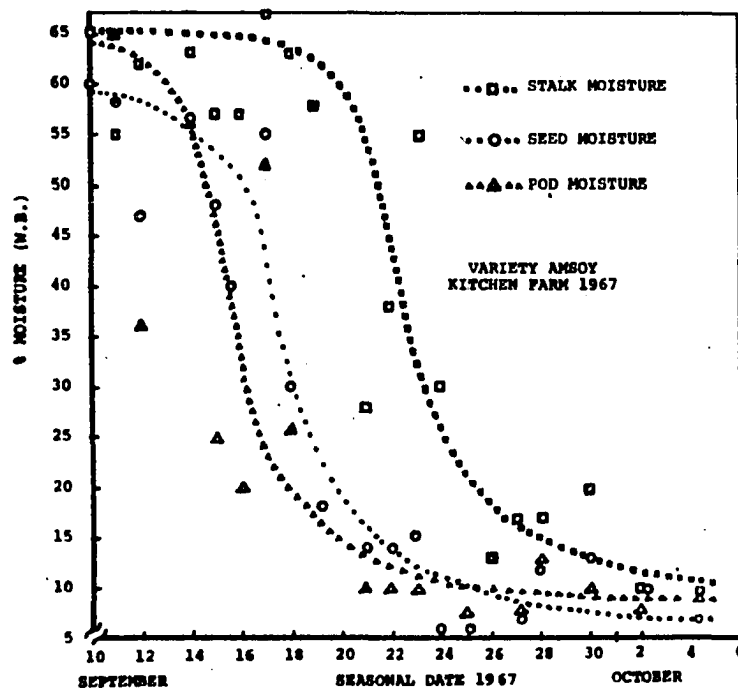


Figure 15. Natural drying rates during 1967 season for seeds, pods and stems, variety Amsoy.

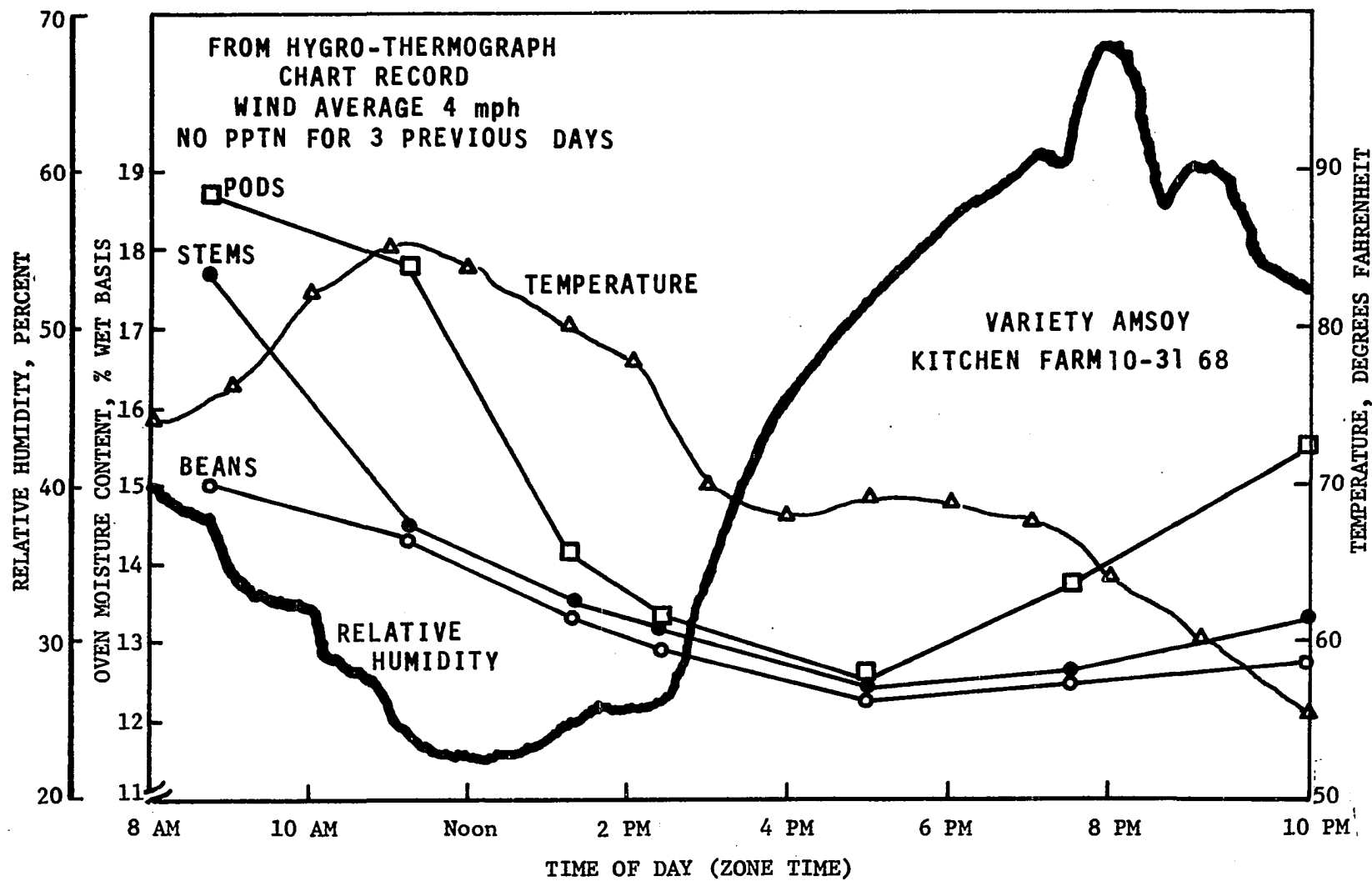


Figure 16. Diurnal variations in weather and moisture content, variety Amsoy.

The influence of diurnal moisture changes on header losses was studied by Lamp et al.

Table 11. Harvesting losses at various times of the day (38).

Time	Seed moisture %	Shatter loss lb/acre	Total loss lb/acre
1 PM	13.9	79	113
8 PM	12.3	75	120
7 AM ^a	13.7 (dew)	24	68

^aCylinder speed had to be almost doubled early in the day to keep threshing losses at a reasonable level.

In summary: header losses were lowest when harvesting began early in the season - usually when the seed moisture content first fell below 14 percent, or as soon as the beans could be threshed. Cylinder speed needed to be adjusted to keep threshing loss at a reasonable level. Lower moisture contents markedly increased header loss. Pre-harvest loss and the chances of adverse weather increase with seasonal delay; so harvesting ought to proceed with all possible haste. Harvest should begin each day when the stalks and pods are dampened with dew, thereby reducing shatter loss. Harvesting at the high moisture contents prior to crop maturity was not feasible with the present threshing cylinder design. Only later in the season was "high moisture" harvesting and artificial drying practicable. Drying is necessary for safe storage and to avoid the economic penalty on beans sold commercially at moisture contents higher than 13 percent.

4.6 Crop Physico-Mechanical Characteristics

4.6.1 Seed weight:

The measurement of soybean header losses may be undertaken by either: (1) picking up and weighing exactly those beans in a sample frame which constitute header loss, or (2) counting the loss-beans where they lie, recording and later converting the beans per frame data to pounds per acre, Figures 17 and 18. Simply counting beans in situ is easier and faster, but requires that a reliable seed weight estimate be made.

A sampling of 1258 Amsoy soybeans indicated that the seed weight frequency distribution tended to be bi-modal, Figure 19. Seeds from a given field of beans tended to fall into a large or small category, depending on pod size, although the hypothesis that this distribution was uniform random within the range 95 to 215 mg (4775 to 2110 beans per pound) could not be rejected at the one percent level, using the chi-square test for goodness of fit, Table A-1¹.

Seed weight was also dependent upon moisture content, Figure 20.

Moisture content of plant parts and seeds was checked by oven drying at 105°C for 72 hours. Seed moisture spot checks were possible using a Delmhorst G-6 electrical resistance moisture meter, calibrated against oven drying and found accurate to within $\pm 1/2$ percent, at moistures up to 20 percent. All moisture contents were determined on a wet sample basis:

$$\text{Moisture Content (MC)} = \frac{\text{weight of moisture removed} \times 100}{\text{wet sample weight}} \quad \%$$

¹Tables delineated by an "A" prefix are to be found in the Appendix.



Figure 17. Team counting header losses within sampling frames. Note straw piles dumped from combine at ends of field plot areas.

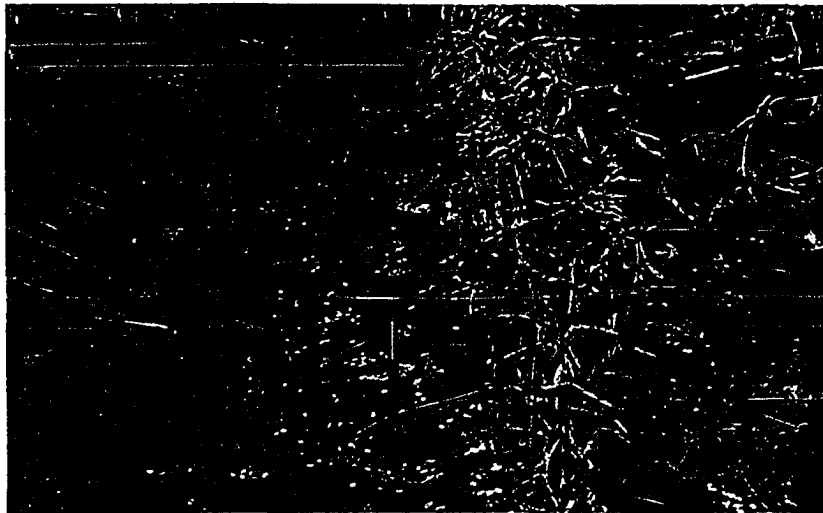


Figure 18. Variety Magna, a large-seeded edible bean, is highly shatter-prone. Cutting higher markedly increases header losses.

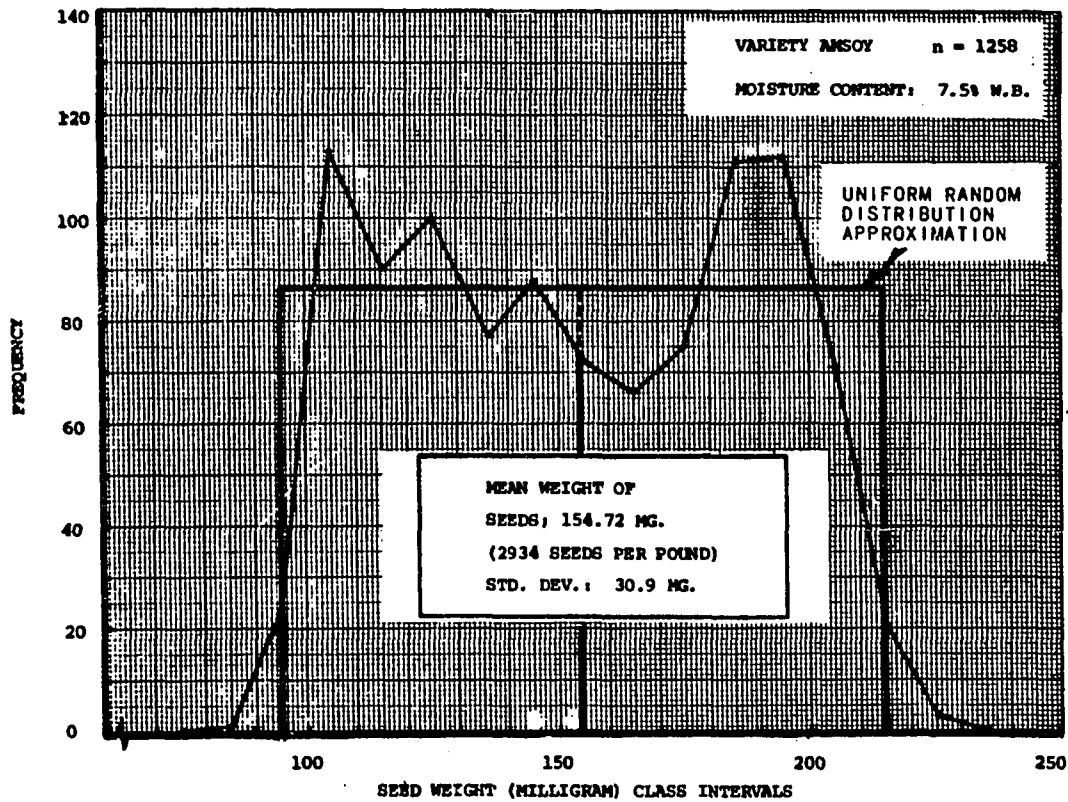


Figure 19. Seed weight frequency distribution.

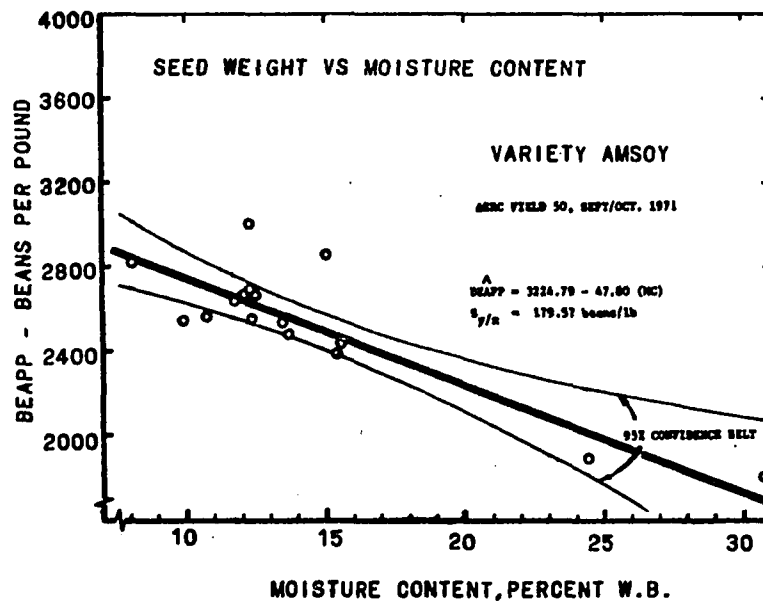


Figure 20. Seed weight vs. moisture content, variety Amsoy 1971.

The dependence of bushel weight upon seed moisture content was also noted. (A bushel weight conversion chart is reproduced in Table A2 from Scott and Aldrich (67).) In view of this moisture dependency, bushel units are avoided in the technical comparisons in this research and are reserved only for general statements on yield, on a basis of 60 lb./bu at 13% MC.

4.6.2 Plant morphology:

Some of the vital statistics of Amsoy soybeans are detailed below:

Table 12. Morphological features of a sampling of Amsoy plants, grown in 30 in. rows with 6.75 plants/ft, 1969.

Average height of plants	40.1 in.
Average height of center of gravity above ground	17.6 in.
Ratio of height of CG to height of plant	0.44
Weight of seed on plants cf. total weight of plants	54.6%
Weight of pods only cf. total weight of whole plants	18.8%
Weight of stems and branches only cf. total weight of whole plants	26.4%
Ratio of seed on branches to total weight of seeds	20.6%
Mean number of seeds per pod	2.29
Typical number of pods per plant	34
Mean down-row deviation of stem from row center	0.66 in.

In Figure 18, attention was drawn to the adverse effect of cutting height on losses. How much would header loss be influenced by height of cut?

The location of all the beans on 10 plants of three varieties was recorded and entered under the seven zones distinguished in Figure 7. Some minor differences in pod distribution, especially in Zone 1, were noted between years for a given variety, and between varieties, Figures 21 and 22. The seed distribution data for the lower 8 in. of the Amsoys of Figure 22 has been elaborated in Figure 23, enabling an estimation to be made of beans remaining at a given cutting height. The data in this plot indicated that, within the 0 to 8 in. height range, the amount of seed left by cutting higher on the stubble increases exponentially, and not linearly, as reported by Weber and Fehr (80). Cutting at 6 in. height would theoretically result in leaving behind 8 to 10 times as many beans as cutting at 3 in. height. In actual field operation the situation is compounded by plant-to-plant entanglement, lodging, etc.

4.7 Mechanically Induced Shatter

Under natural conditions the pendant pods on the bush of native soybean types tended to dehisce as soon as they matured. Plant breeders have selected against this character in the varieties bred for modern commercial production. Pre-harvest loss was low in this research; for example, three weeks after maturity in 1971, variety Amsoy had less than 15 lb./acre pre-harvest loss (0.5 percent of gross yield), with about half of this loss being detached pods. [Lodging was severe, however, with up to 30 percent of the stems and branches leaning below horizontal in parts of the same field.]

When the combine attacks the crop, shatter losses occur. If the machine is poorly operated and maladjusted, then shatter losses may be the

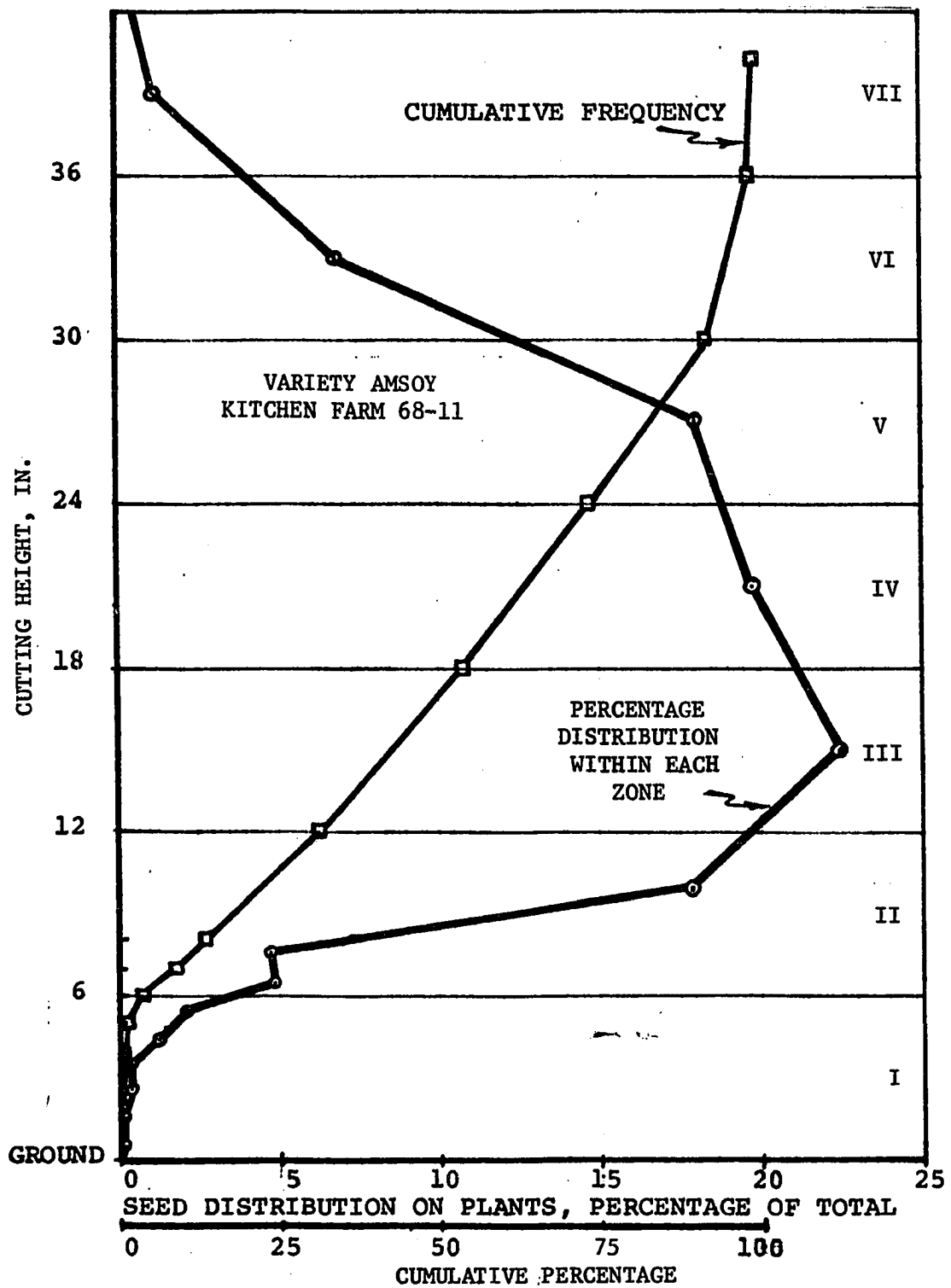


Figure 21. Seed distribution on plants, variety Amsoy, 1968.

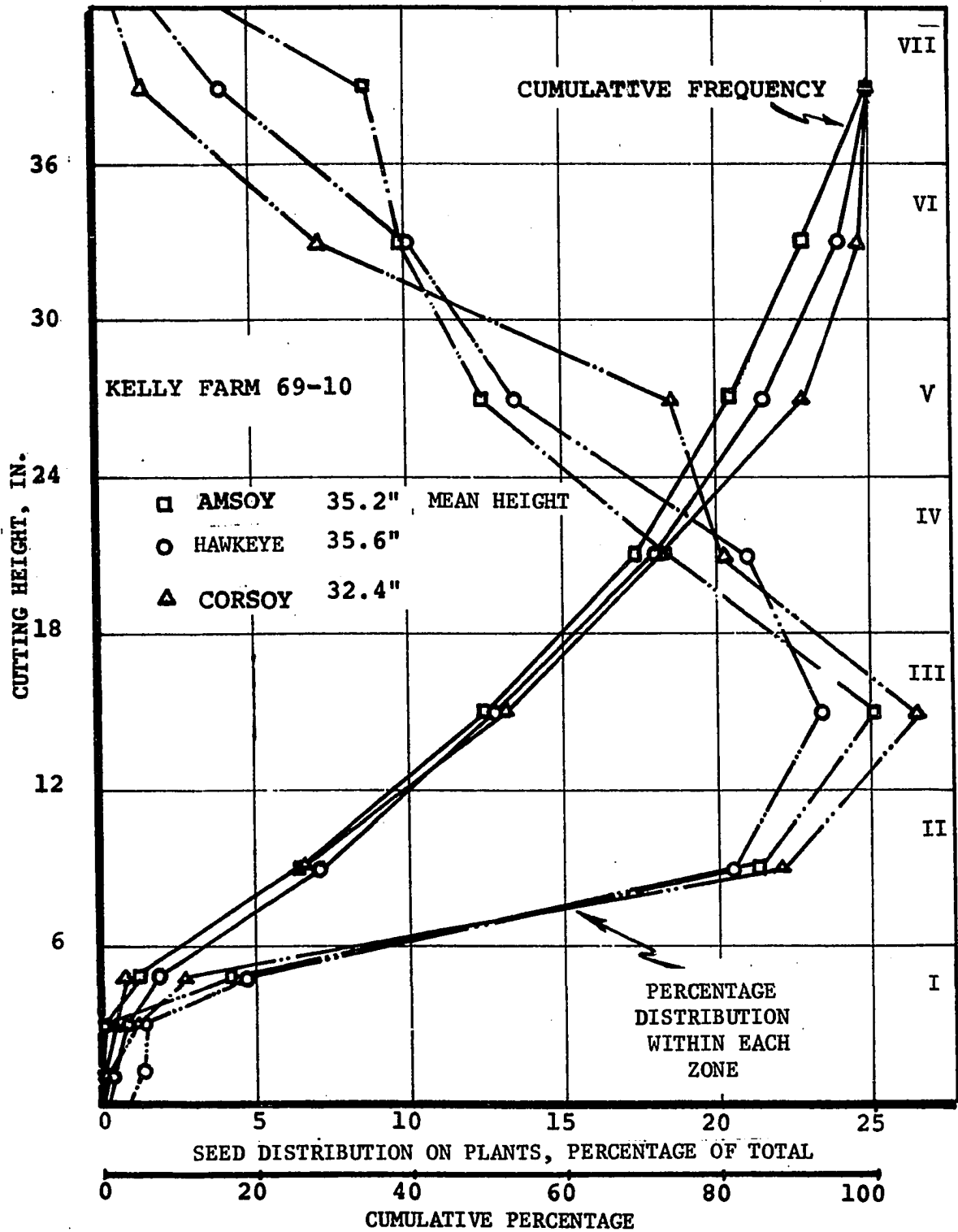


Figure 22. Seed distribution on 10 typical plants of three soybean varieties, 1969.

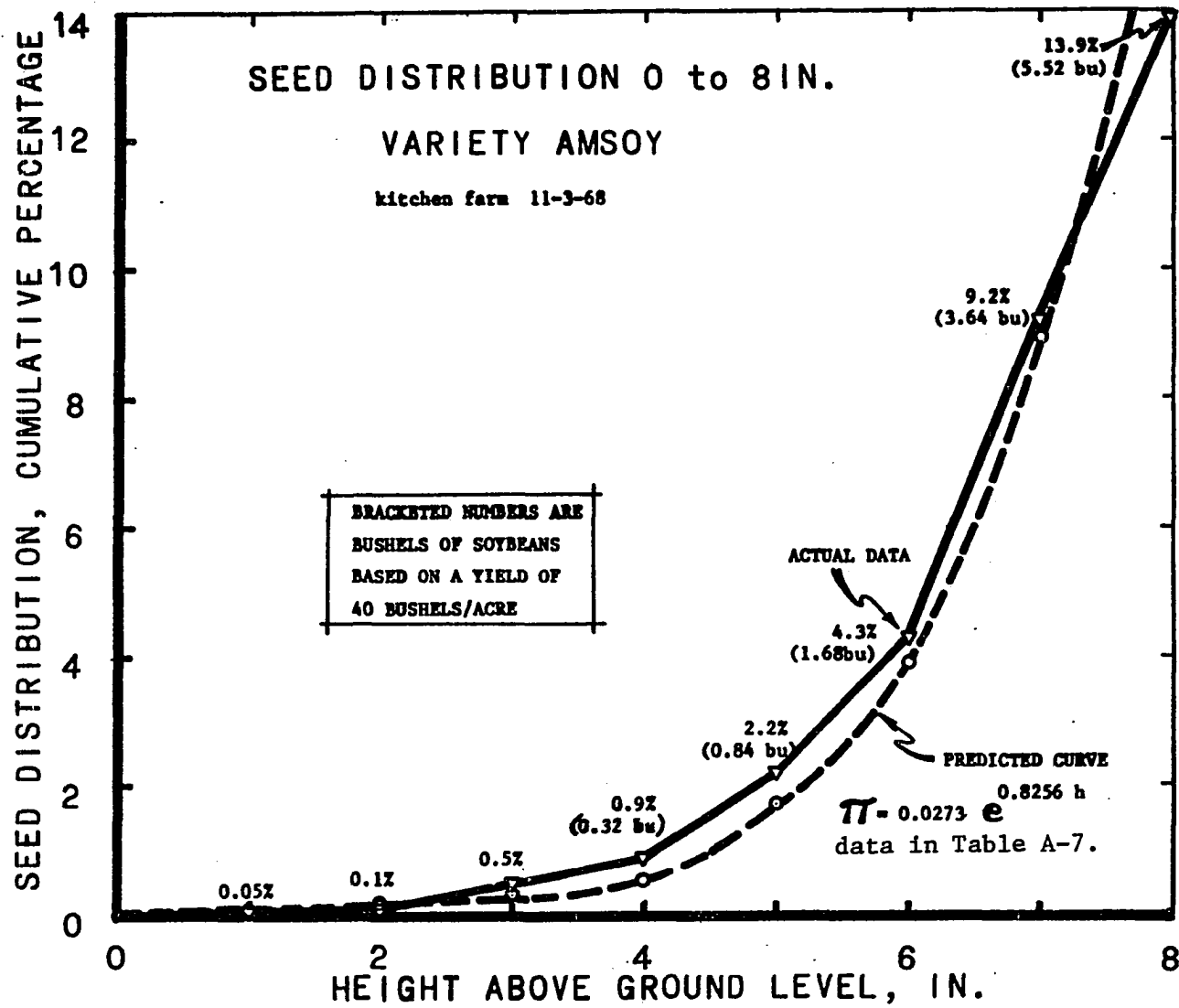


Figure 23. Seed distribution on lower 8 in. of plants, variety Amsoy, 1968.

largest single loss. The distinction, however, between beans shattered from pods which were stripped off or cut open by the cutterbar, and beans shattered by other causes, cannot be made in field evaluations.

Several techniques were developed to study the mechanical shattering propensity of pods, namely, vibration, centrifugation, tension and compression; Figures 24 and 25.

4.7.1 Vibration:

Cantilever mounting and vibration near the base of soybean stems proved to be a very poor method of inducing shatter. Individual plants were rigidly clamped in the horizontal position and an electro-mechanical shaker was attached to the stem 1-1/2 in. from the clamp, Figure 24A. Two Physitech Model 39 electro-optical tracking units were coupled to the vertical and horizontal beams of a Tektronix dual-beam oscilloscope. With these instruments motion of the stem and shaker could be recorded independently. Vibration at the first three resonant frequencies produced closed loop (Lissajous) figures on the oscilloscope. As forcing frequency was increased, the Lissajous figures became less distinct. The fourth harmonic was distinguishable by stroboscopic observation.

Table 13. Predicted and actually measured resonant frequencies of a cantilevered Amsoy stem, 9% MC.

Mode	Theoretical ^a (Hz)	Measured (Hz)	% Error
First harmonic	3.98	8.05	-50.5
Second harmonic	24.9	31.5	-20.9
Third harmonic	69.8	85.0	-17.8
Fourth harmonic	136.5	136.5	0

^aTheoretical values were determined from continuous cantilever beam vibration theory, see Table A-3.

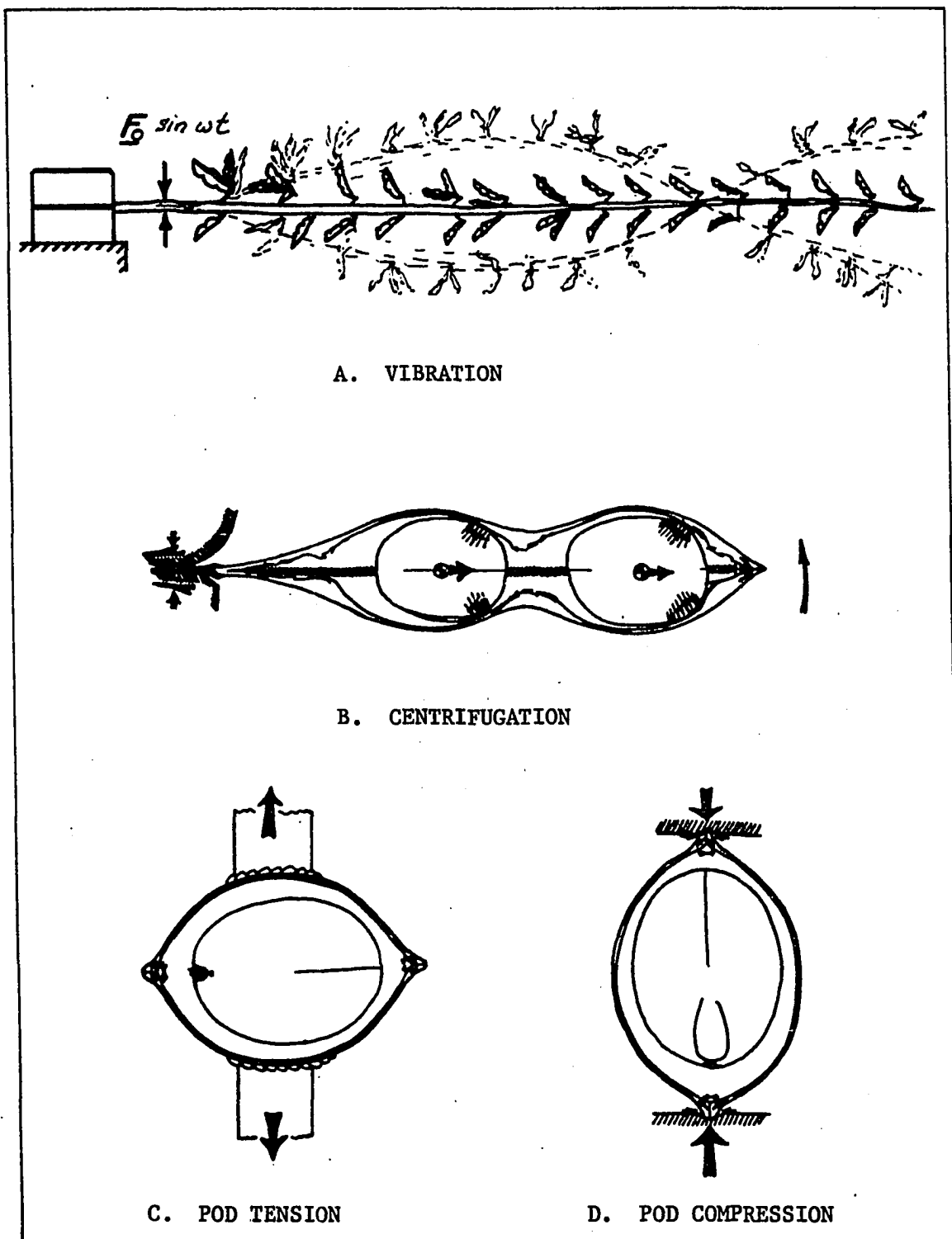
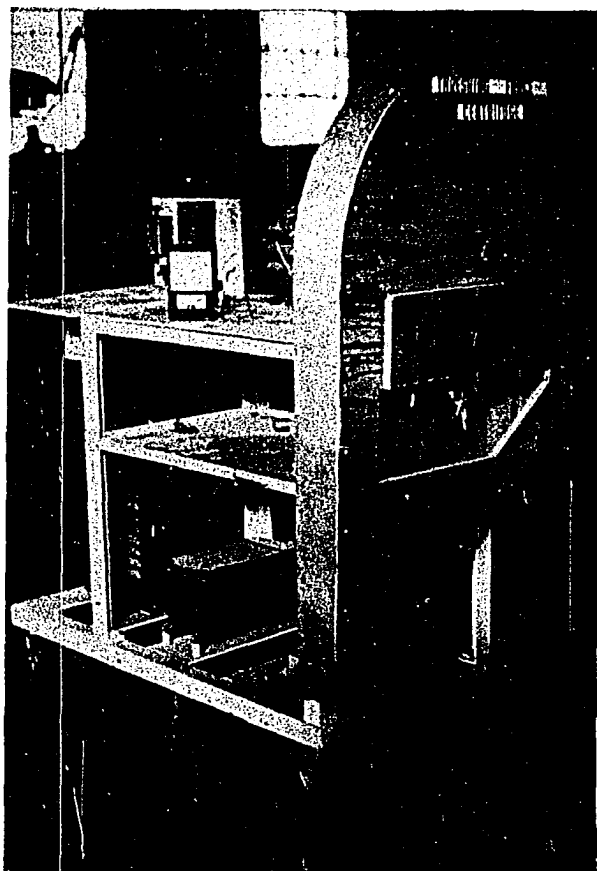
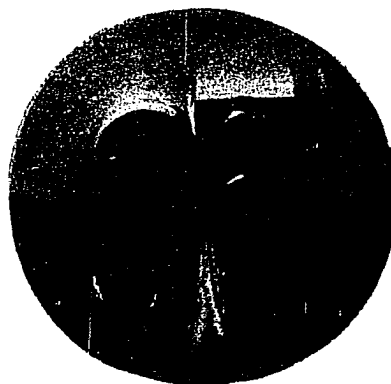


Figure 24. Mechanically induced shatter.



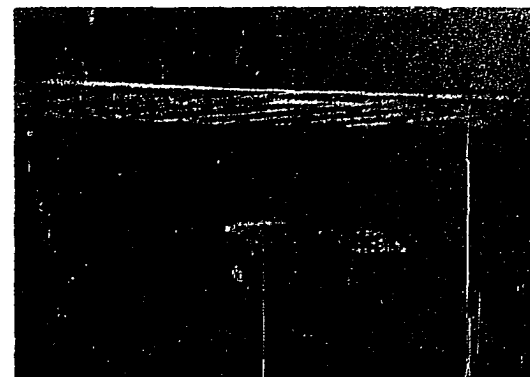
A. Centrifugation. 3-HP DC variable-speed electric motor drive.



B. Inset shows eccentric cam clamp.



C. Pod tension test on Instron TBM tensile tester.



D. Pod compression tests, anvils closed on pod seams.

Figure 25. Mechanically induced shatter; instrumentation.

This shaker produced some shatter. Maximum shatter, or threshing, occurred in several pods near the anti-nodes at frequencies around 45 Hz. At other frequencies all pods on stalks withstood prolonged resonant vibration exposure - up to several thousand cycles - without whipping off pods or releasing beans from pods.

The shaker was also used to shake individual pods. Three-bean Amsoy pods exhibited natural frequencies between 4 to 7 Hz, and again very few pods shattered, provided that the vibrating pod did not accidentally contact a hard surface.

4.7.2 Centrifugation:

A centrifuge was constructed, Figures 25 A and B, and 10 pods were clamped to the periphery of the disc. The degree of shattering was recorded as the disc speed was increased by 100 rpm increments. The results of several different trials are illustrated in Figure 26 (calculations are based on the data and formula in Table A-4). The "8% Amsoy" plot represents tests on beans which had been left in the field over the 1969 winter. These pods had lost their resiliency and were more readily shattered, although they appeared to have kept reasonably well.

4.7.3 Pod tension:

Aluminum foil "tags" were glued onto pods with epoxy cement and the pod carpels pulled apart by the Instron Model TTBM tensile tester, Figure 25C. The loading rate was 1 cm/min and failure proceeded as shown in the typical chart reproduced in Figure 27.

4.7.4 Pod compression:

This type of testing required least preparation. The pods were inserted, with suture vertical, between anvils built for the Instron

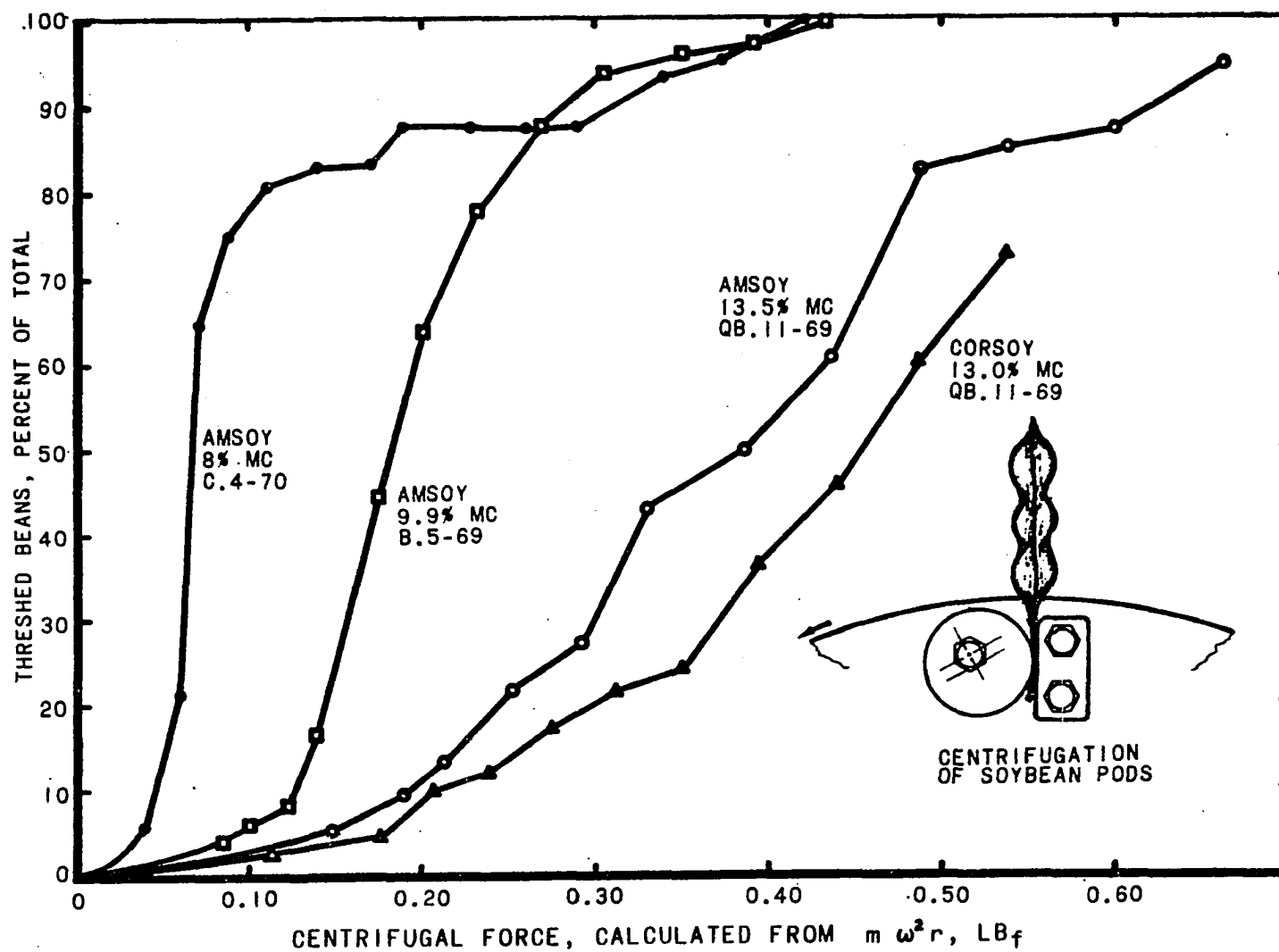


Figure 26. Centrifugation of soybean pods.

SORBEAN POD OPENING FORCE - TRACTION ON MIDDLE ZONE OF THREE BEAN POD, LATERAL LOADING.

LOADING RATE: 1 CM/MIN, INSTRON TTB

CHART SPEED : 50 CM/MIN, 2 KG SCALE

POD MOISTURE : APPROXIMATELY 10% M.B.

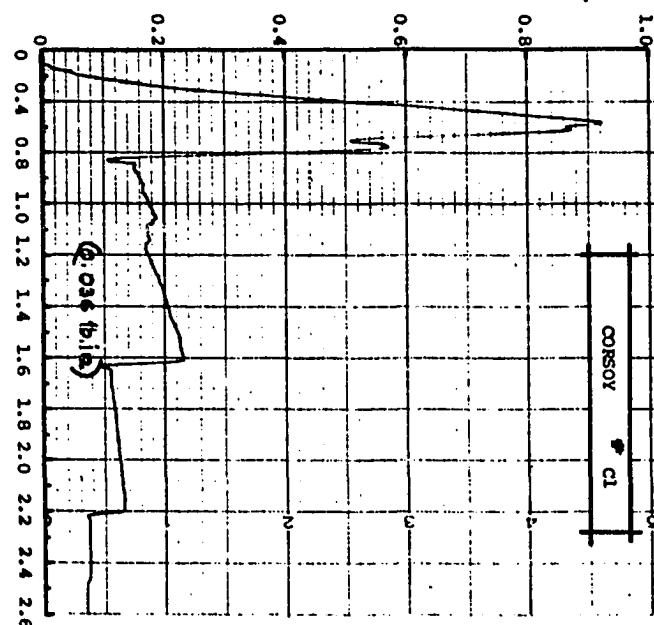
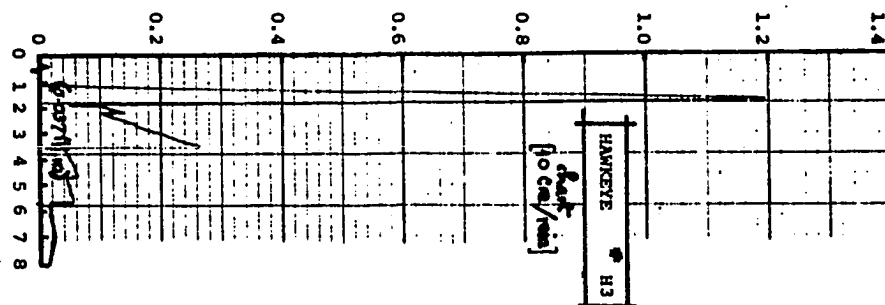
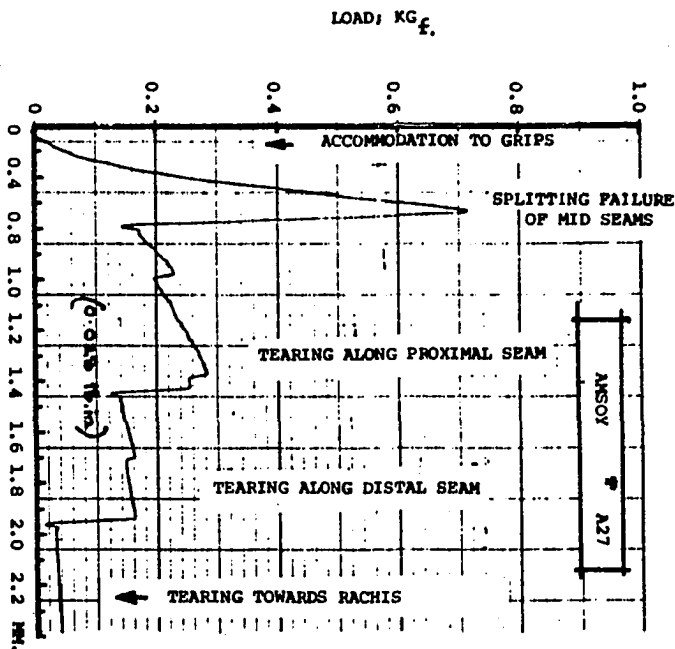
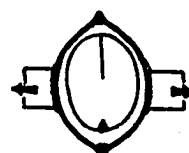


Figure 27. Pod tension. Charts reproduced from Instron tests.

tester, Figure 25D. The loading rate was 1 cm/min and applied up to that point when compression of the bean began, Figure 28.

4.7.5 Pendulum impact on pods:

Hoag conducted experiments using a small ballistic pendulum and instrumentation to measure the impulse on mounted soybean pods (28). Definite conclusions were not reached concerning impact velocity and energy absorption, but more energy was apparently required to cause shatter at higher velocities. There was a decrease in energy necessary to cause shatter as MC diminished. The mean energy of shatter of 10 to 15% MC Amsoy pods was 0.334 in. lb. Average imparted impulse was 0.0184 lb. sec in 1969, and 0.0281 lb. sec. in 1970 at these moisture levels, and the magnitude of impulse diminished at the higher impacting velocities.

4.7.6 Effect of moisture content on pod compressive force:

The relationship between the pod compressive shatter and seed moisture at a loading rate of 1 cm/min was observed, Figure 29. The relationship between header loss and moisture content found in header lab tests is also shown. Note the approximately inverse relationship between pod compressive force and header loss at a given MC.

4.7.7 Effect of pod size on pod compressive force:

Pod compressive shatter and pod depth were positively correlated, although the correlation was poor, Figure 30.

4.7.8 Partially dehisced pods - cryptic shatter:

In spite of all the pod properties which might be measured in the lab there is one elusive source of shatter which could be of importance in field practice. The term "cryptic shatter" has been coined for those pods

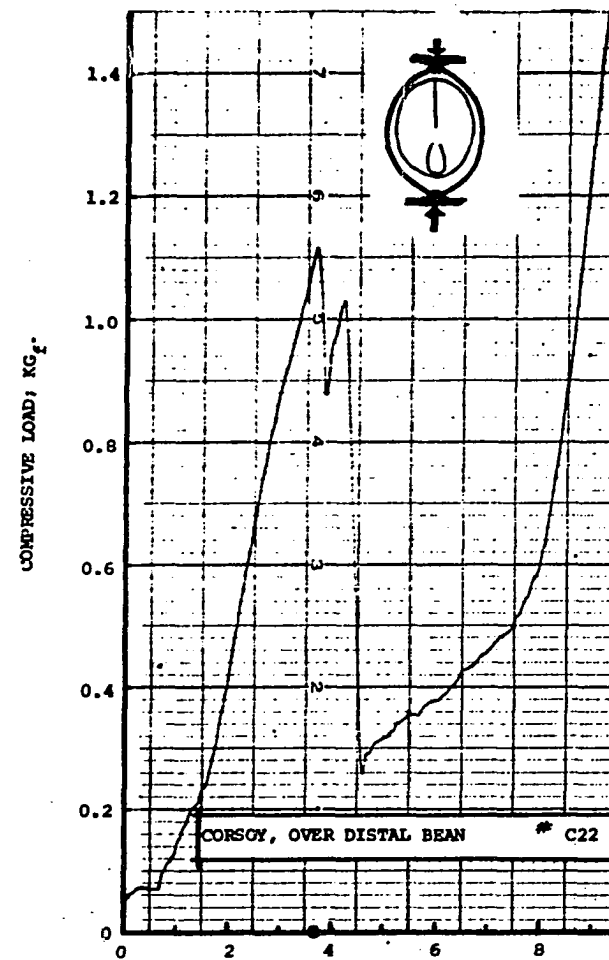
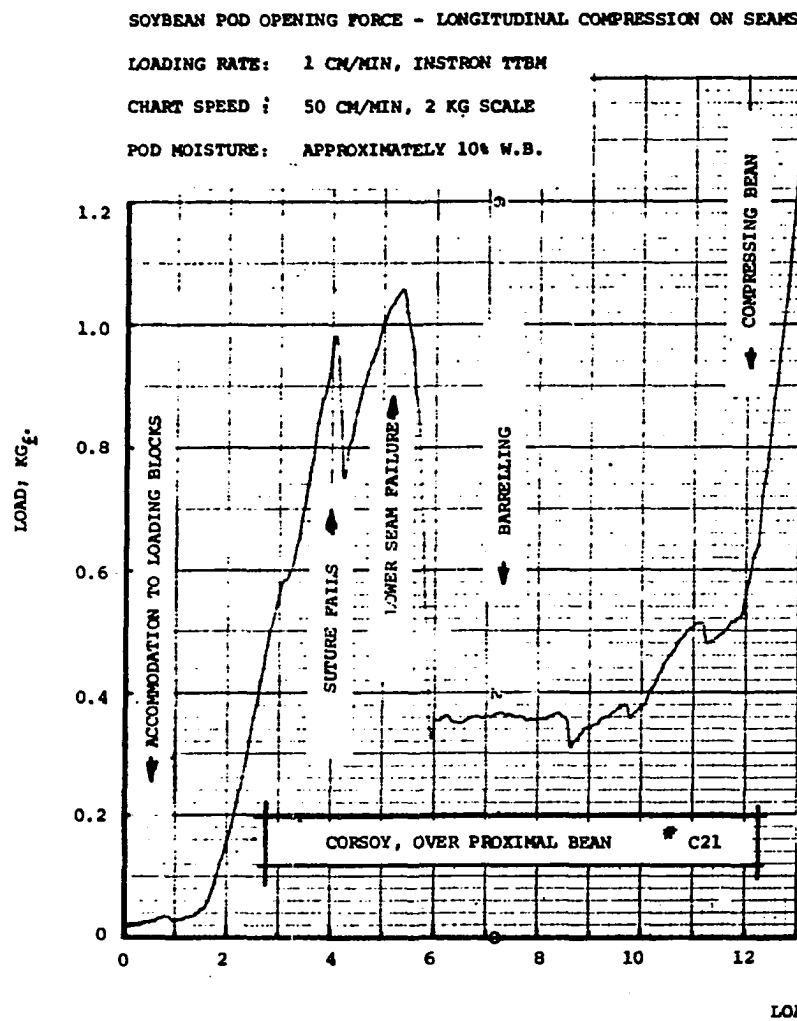


Figure 28. Pod compression. Charts reproduced from Instron tests.

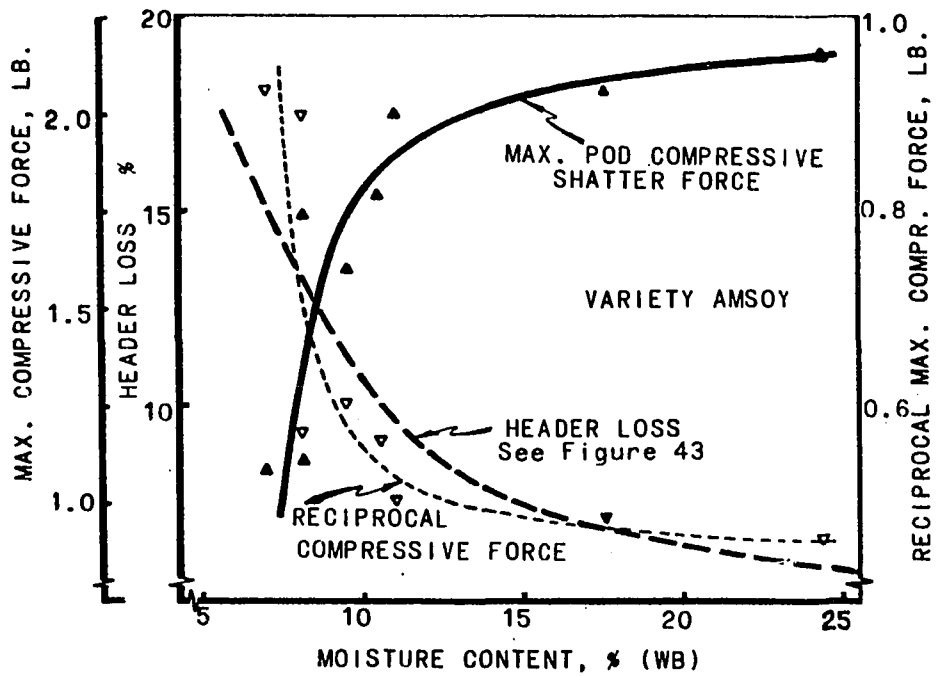


Figure 29. Mean pod compressive shatter force vs. moisture content, variety Amsoy, 1971.

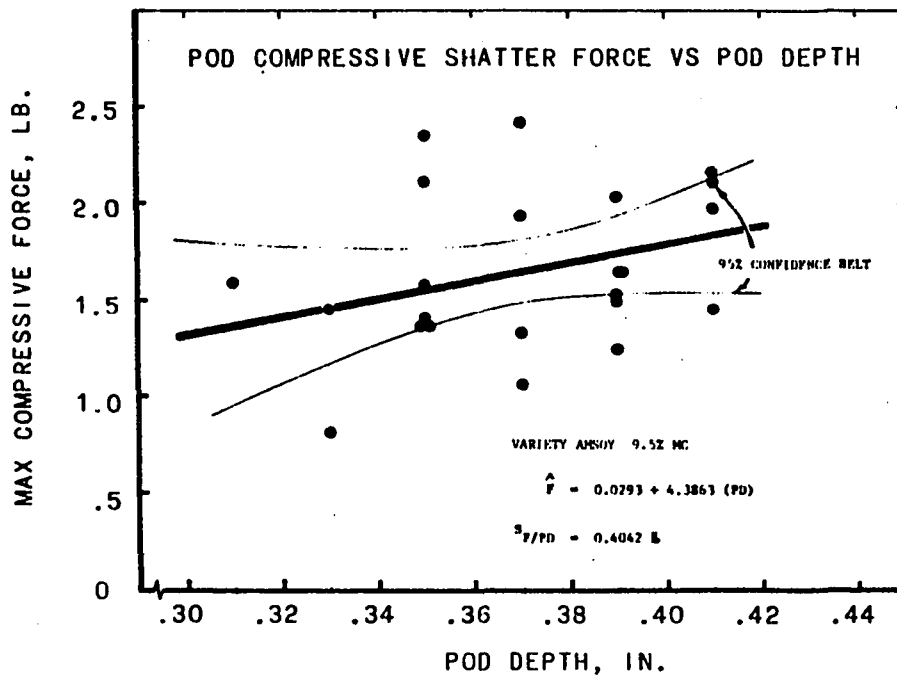


Figure 30. Mean pod compressive force vs. pod depth, variety Amsoy, 1971.

which have the suture partly opened. Plants having such pods cannot be removed from the field without causing these pods to shatter. If only one pod on alternate plants fell in this category the potential shatter loss would be 1 bu/acre, or 2% loss in a 50 bu/acre field. It was estimated that in 1971 a cryptic shatter loss of about this magnitude existed in the Amsoy plots.

4.7.9 Summary of results of mechanically induced shatter tests:

Inevitably, as with all visco-elastic materials, loading rate and moisture content affect the results. Any standard tests on the behavior of such biological materials as soybean pods require close control over these variables. There are limitations on the extent to which a "static" test can be used to represent a dynamic situation, as in the case of a 1 cm/min compression test used to predict combine shatter. Nevertheless, the compression test was informative and easiest to perform. It is anticipated that with further study a reasonably good correlation between the shattering propensity of a variety and a "compressive shatter factor," such as the reciprocal of pod compressive shatter force, will be found.

Table 14. Representative values of force and energy required for mechanically inducing shatter in variety Amsoy.

<u>Vibration</u>	<u>Max. stem acceleration field</u> (below threshold for pod shatter)	
$X = X_0 \sin wt$	(Accel) max. = $(2\pi f)^2 \cdot \frac{X_0}{G} = 280 \text{ G's at resonance}$	
<u>Centrifugation</u>	<u>Ten percentile force</u>	
$F = m w^2 r$	9.9% MC	0.125 lb. (298 G's)
	13.5% MC	0.191 lb. (451 G's)
	<u>Average force</u>	
	9.9% MC	0.172 lb. (411 G's)
	13.5% MC	0.387 lb. (916 G's)
<u>Tension</u>	<u>Average force</u>	
1 cm/min loading rate	9.5% MC	1.44 lb. tension
(Pod splitting at seams)	<u>Average energy</u>	
	9.5% MC	0.028 in. lb.
<u>Compression</u>	<u>Average force</u>	
1 cm/min loading rate	9.5% MC	1.06 lb. compression
(Pod splitting at seams)	<u>Average energy</u>	
	9.5% MC	0.035 in. lb.
<u>Impulse</u>	<u>Average impulse</u>	
Hoag's ballistic pendulum (28)	10-15% MC	0.0184-0.0281 lb. sec
	<u>Average energy</u>	
	10-15% MC	0.334 in. lb. ^a

^aThe energy expended in compressing and accelerating the beans was not isolated; this probably accounts for the high energy figure quoted.

5. EXPERIMENTAL PROCEDURES FOR EVALUATING THE HEADER

A uniform terminology pertaining to the subject is desirable. The first three of the following definitions are adapted from ASAE Tentative Standards (2), the remainder were proposed for use in this study.

5.1 Operational Definitions

- (a) Header or Gathering Width - the distance between the center lines of the outermost divider points, ft.
 - (b) Cutting or Cutterbar Height - the mean height of the forward section of a sickle¹ section above the plane on which the machine is standing, with combine tires at normal inflation and grain bin unloaded, in.
 - (c) Stubble Length - Length of cut plant stalk attached to the ground immediately after harvesting. Measured above row center mean surface, parallel to the stalk, in.
 - (d) Gross or Total Yield - represents the weight or volume of all the mature seed (p) produced in the field, lb./acre or bu/acre.
 - (e) Net Potential Yield (YLDNP) - represents the weight of all the seed which is potentially available to the machine, lb./acre.
- $$\text{YLDNP} = \text{total yield} - \text{natural loss}, \quad (5-1)$$
- also
$$\text{YLDNP} = \text{bin yield} + \text{all machine losses}. \quad (5-2)$$
 - (f) Natural or Pre-Harvest Loss - the weight or fraction of beans and pods shattered or dropped free and on the ground before harvesting (some

¹The term "sickle" was reserved by ASAE for the reciprocating component of the header for cutting the crop. "Cutterbar" is the generic term for all cutting mechanisms in this work; "knife," "blade," or "section" for one of the cutting elements.

of these will be removed by birds, insects and vermin), lb./acre or percent.

(g) Bin Yield (BINYE) - seed sample weight in the grain bin or sample bucket, harvested from a known crop area, lb./acre or lb./plot.

(h) All Machine Losses = header + through-combine (cylinder + separating + cleaning losses + body leakage) losses, lb./acre. (5-3)

(i) Header Loss = shatter loss (chargeable to machine) + stalk loss + lodged loss + stubble loss, lb./acre. See Figure 31.

(j) Shatter Loss - the number or weight of free beans and beans in pods detached from the stalk which are chargeable to the machine (=all shatter losses - pre-harvest loss), beans/sampling frame (BPF) or lb./acre.

(k) Stalk Loss - the number or weight of beans in pods attached to stalk pieces which were cut but not collected, BPF or lb./acre.

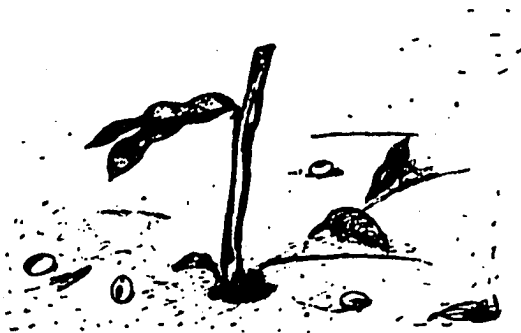
(l) Lodged Loss - the number or weight of beans in pods attached to stems or branches which were not cut but which slipped under the cutterbar and are abnormally longer than the stubble, BPF or lb./acre.

(m) Stubble Loss - beans in pods attached to the free-standing stubble left by the machine, BPF or lb./acre.

(n) Lodging - fraction of crop lying flat, expressed as actual percent of stems and branches horizontal or below horizontal, percent.

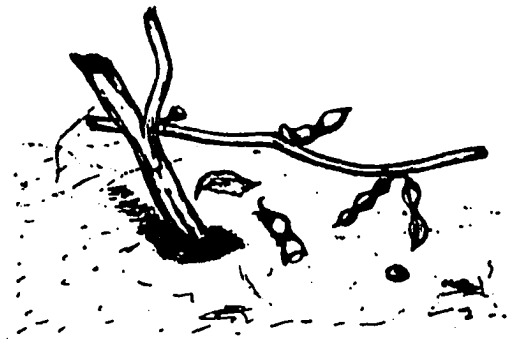
(o) Physiological Maturity - an Agronomic term (to be distinguished from "Maturity," see (p)) that refers to the period in the plant life cycle when maximum dry matter accumulation in the seed has been attained - usually seven to ten days before harvest can begin.

(p) Maturity - refers to the point in the season when harvesting can begin - generally considered practicable when seed moisture first falls to



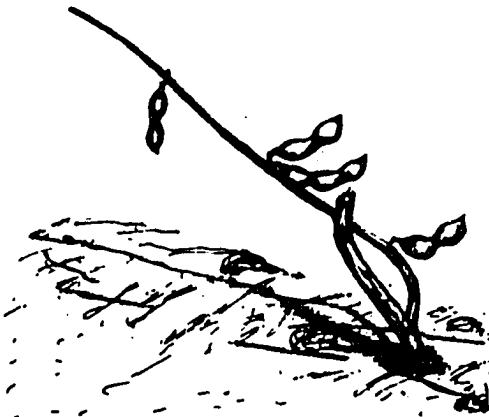
SHATTER LOSS

THOSE LOOSE OR FREE BEANS AND
BEANS IN PODS DETACHED FROM THE
PLANT, CHARGEABLE TO THE MACHINE.



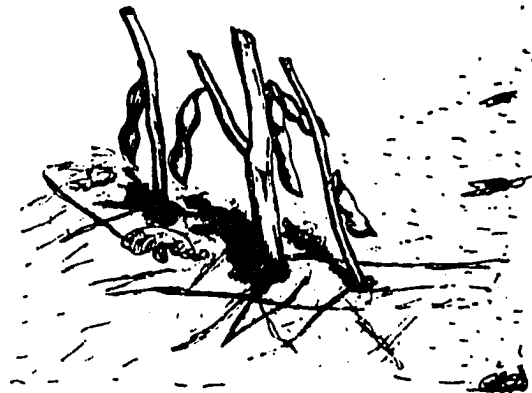
STALK LOSS

BEANS IN PODS ATTACHED TO STALK
PIECES WHICH WERE CUT BUT NOT
COLLECTED ('CUTTERBAR' LOSS).



LODGED LOSS

BEANS IN PODS ATTACHED TO STALKS OR
BRANCHES ABNORMALLY LONGER THAN THE
STUBBLE, WHICH SLIPPED UNDER THE
CUTTERBAR.



STUBBLE LOSS

BEANS IN PODS ATTACHED TO THE FREE-
STANDING STUBBLE LEFT BY THE MACHINE.

Figure 31. Combine header losses in soybeans defined.

14% MC. The maximum allowable MC of USDA No. 1 market grade soybeans is 13%. Soybeans can be harvested at moisture levels somewhat higher than this without noticeably increasing seed damage during threshing.

(q) Reel Index - ratio of reel peripheral speed to combine forward speed. Care should be used to select the correct kinematic radius for the purposes of calculating reel peripheral speed.

(r) Cutterbar Advance Ratio or Advance Ratio - ratio of average cutting blade speed to combine forward speed.

5.2 Breakdown of Soybean Losses by Causes :

Table 15. Breakdown of soybean losses .

Type of loss	Causes
Pre-harvest (not chargeable to machine)	Early lodging, before flowering. Late lodging, after fruiting, resulting in pod rotting or removal from lodged stems and branches. Pod drop due to disease. Loss due to rubbing and whipping. Seed shatter and partial opening due to wind and thermal stresses.
Header	Pod cutting and stripping. Stem double-cutting. Branch cutting and not collecting. Lodged stems and branches sliding under cutterbar. Mechanical shattering - reel, cutterbar and auger.
Through-combine	Unthreshed pods and free seeds in the straw in the combine efflux. Body leakage.

5.3 Response Variables

The response variable of primary concern is Header Loss and the response variable of secondary concern is Header Capacity.

5.3.1 The primary response variable - Header Loss:

The primary response variable can be expressed in dimensionless terms, at the same time accounting for the influence of total yield variations between plots:

$$\pi_1 = \frac{\text{Total Header Loss}}{\text{Net potential yield}} = \frac{\text{Sum of individual Header Losses}}{\text{YLDNP}} \quad (5-4)$$

Individual loss ratios:

$$\pi_{1,1} \text{ Shatter loss} = \frac{\text{Machine shatter loss contribution}}{\text{Net potential yield}}$$

$$\pi_{1,2} \text{ Stalk loss} = \frac{\text{Stalk loss contribution}}{\text{Net potential yield}}$$

$$\pi_{1,3} \text{ Lodged loss} = \frac{\text{Lodged loss contribution}}{\text{Net potential yield}}$$

$$\pi_{1,4} \text{ Stubble loss} = \frac{\text{Stubble loss contribution}}{\text{Net potential yield}}$$

Note that

Net potential yield = Bin yield + Header Loss + through-combine losses,

$$\text{YLDNP} = \text{BINPA} + \text{THLPA} + \text{TRUCOL} \text{ (lb./acre units)} \quad (5-5)$$

5.3.2 The secondary response variable:

Header Capacity = Throughput at working rate, lb. crop/min

$$= \text{Header Width} \times \text{Forward Speed} \times \text{Bin Yield} \times \text{unit conversion factor; lb./min} \quad (5-6)$$

i.e. header capacity is a function of forward speed, for a given width and operating conditions.

Usually the horsepower required by the combine header is low (less than one-tenth of available engine power (61)) and the power demand is

comparatively steady in soybeans. Header power is not of direct concern in this work.

5.4 Pertinent Independent Variables

These fall into three categories:

5.4.1 Machine parameters:

(a) Operational

Forward speed (or "rate of advance" in the lab), mph

Reel speed, rpm

Auger speed, rpm

Cutterbar speed, rpm, spm (strokes per min), or fpm

Cutting speed, fpm

Reel position, forward and above knife, in.

Header height controller setting and response etc.

(b) Geometric

Reel : diameter, number of bars, tines

Cutterbar : Guard spacing and shape, knife section shape and clearance, sharpness, and stroke etc.

Divider and crop lifter geometry

Auger : diameter, pitch, location, clearance, center tube diameter etc.

Platform : slope, length, depth.

5.4.2 Crop characteristics:

Variety

Row spacing, in.

Planting density, plants/acre or plants/ft along row

Planting date

Cultivation practices, soil profile and bearing capacity

Weed infestation level, plants/acre or plants/sq ft

Harvesting date and time of day.

5.4.3 Individual plant characteristics:

Seed, stalk, and pod moisture contents

Branching propensity

Extent of lodging, percent

Height of plant, in.

Height under lowest seed, in.

Height of center of gravity, in.

Down row deviation, in. from center line

Shatterability of pods

Stalk strengths

5.5 Field Testing Combine Headers

5.5.1 Plot size:

Total yield was assessed from the sum of the bin yield (collected in a bushel basket under the outlet of the clean grain cross conveyor on the combine) plus all losses.

To minimize error in measuring bin yield to less than 1% - a measurement which has to be made quickly and readily on the machine in the field environment - the plot size should be sufficiently large so that bin yield is over 100 times the least scale division of the weighing scale, i.e. 10 lb. minimum. In a 35 bu/acre crop and with a 10-ft. wide header, this amount of yield would be produced from a 26 ft long plot (if losses were 20% of total yield).

For convenient conversion to lb./acre units most of the field plots were trimmed to 43.56 ft length, i.e. a 1/100 acre swath. Standard row spacing for the trials was 30 in.

5.5.2 Pre-harvest loss:

Pre-harvest loss was assessed by sampling beans and pods on the ground in 3 ft x 5 ft areas in randomly selected unharvested rows adjacent to the plots.

5.5.3 Extension methods of measuring header losses unacceptable:

Extension Service pamphlets from Ohio State University and the publications of some other researchers (8, 10, 49) have advocated that header losses be measured by the following procedure (paraphrased):

Stop combine where crop is typical of entire field, clear the header. Back up combine about 15 ft. Gathering unit losses are determined by placing the rectangular frame in the space between the parked combine and the uncut beans.

While there is no desire to discourage farmers from conducting spot checks on their header losses, as enabled by this method, it has serious drawbacks for the type of investigations involved in this study.

For machine comparisons the method is unsatisfactory for the following reasons:

- (1) The area available for sampling is too small.
- (2) Combine speed over the area sampled, where the machine is decelerating to a standstill, cannot represent normal operation. While the header is clearing, the reel flails the plants ahead.
- (3) Impracticable at speeds over 3 mph.
- (4) Plants fall out of the header if machine is jerked to a stop and

backed up.

- (5) If any replications are involved, would take too long.
- (6) No control over bin yield determinations. Bin yield varies considerably from place to place and should be measured over the loss-assessing area.

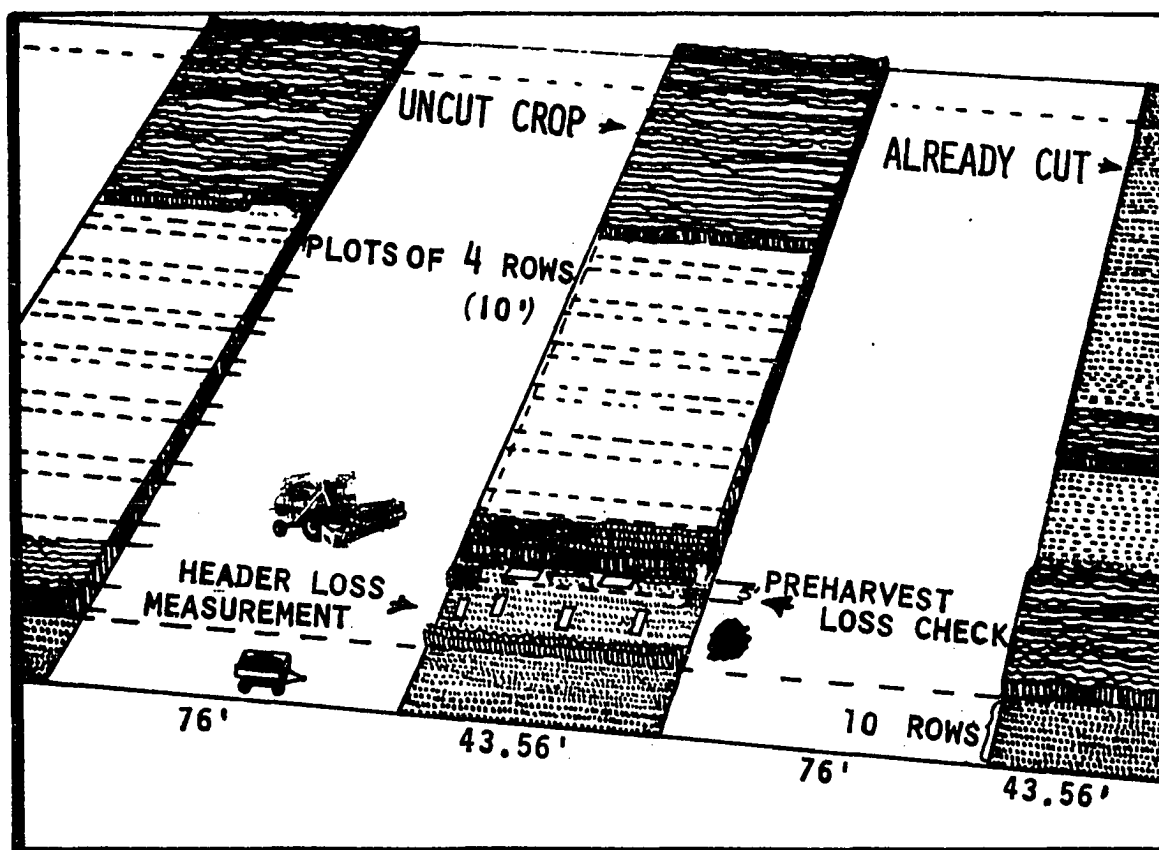
The preferred method, used here, was to run the combine completely over a predesignated and measured area, at the same time preventing the efflux from falling on the plot. This efflux material was collected in an 8 ft wide open-sided canvas and frame, and then dumped outside the plot area, Figure 32. What remained on the plot represented header and pre-harvest losses, disturbed only by the combine wheels (with the low ground pressures of the combine tires, losses were not obliterated). From 40 to 80 ft wide turn alleys were left for maneuvering at each end of the plot.

5.5.4 Loss - sampling frame size:

A separate experiment was conducted in 1967 with USDA Agricultural Engineers (see Table A-5) to determine the smallest sampling frame size (FRASI) and number of sub-samples needed for a given degree of experimental precision. On the basis of this experiment the decision was made to use sampling frames 1/10,000 acre in area (60 in. x 10.5 in. inside dimensions), thrown down four times at random locations across two rows within the plot. Individual loss data was categorized and entered on standard data forms in beans per frame (BPF) units.

5.5.5 Experimental designs:

Experimental designs and layout were planned before planting in consultation with ISU Statistical Laboratory staff. Randomized complete



Typical Field Plot Layout. Bin yield, the combine losses, pre-harvest loss, combine speed, cutting height, and stubble length are measured in the field.

Personnel Required

Driver
Supervisor/Recorder
Timer
Yield Measurer
Loss Samplers
Dump Supervisor

Equipment

Combines, bin sample weigher
Stopwatch
Measuring tapes
Measuring loss frames
Moisture sample bottles
Labels, stakes

Figure 32. Field measurement of soybean harvesting losses.

block or multi-factor factorial designs with replications were generally used. The size of an experiment and number of replications were chosen so that the whole operation could be conducted in one afternoon. Experiments were normally not conducted earlier than two p.m., so that diurnal moisture variations would be minimized. Plots were marked using coded stakes and were separated from each other by at least two rows.

5.5.6 Typical field procedure:

After the machine was serviced and warmed up, several trial runs were made in adjacent plots where operational settings were checked. Pre-harvest loss was assessed. The experiment then proceeded:

- (1) Attach bushel basket to clean grain spout of combine.
 - (2) Attach discharge catching frame and canvas to rear of combine.
 - (3) Run combine through plot (same driver for all tests).
 - (4) Stop 30 to 40 ft beyond plot, leave machine running one minute.
 - (5) Dump efflux, or store in container for through-combine loss assessment when required.
 - (6) Measure BINYE on scale hooked on combine.
 - (7) Collect sample bottle of these beans, seal and label for later moisture and beans/lb. assessments.
 - (8) Enter data, move combine to next plot according to experiment plan.
- After all the machine work has been done, then
- (9) Throw down the four frames in the plot, measure, and record losses (two operators each measuring two frames), BPF units.
 - (10) Measure stubble length of 20 stalks in the plot (STUBBL).
 - (11) Punch data onto cards and send in for IBM 360/65 computer conversion

to appropriate units and ratios, see Figure 33, and subsequent statistical analysis, using ISU Statistical Laboratory Computer Library routines. Covariate analyses, with stubble length as covariate, as well as analyses of variance, were usually run.

5.6 Lab Testing

The combine has to cut so low in soybeans that it is impracticable to place a loss-catching frame under the header or collecting sheet on the ground, to collect header losses. Field measurement of header loss is extremely tedious in soybeans.

Soybean plants can be kept for years in storage. These considerations make the soybean an eminently suitable crop for a study of gathering problems in the lab.

A header lab testing facility was built and installed in the Agricultural Engineering Research Laboratory, Ames.

Advantages sought in designing the facility and conducting tests indoors were:

- (1) The time, labor and cost involved in the evaluation of header performance should be reduced compared with field testing.
- (2) A smaller sample size, yet higher statistical reliability in reporting data.
- (3) The weather factor is eliminated, enabling a continuity in the testing program. This was to prove especially significant in the 1970 season when wet fields and high moisture beans impeded field harvest trials.
- (4) Better control over the experiments, with more comfortable conditions

```

SJVN      14244GRAQUICK ,TIME=5,PAGES=10
C ***** PROGRAM TO TABULATE HEADER LOSS DATA AS PERCENTAGE OF
C      NET POTENTIAL YIELD FOR FIELD TRIALS OF COMBINE HEADERS
C      IN SOYBEANS . ***** GRAEME R. QUICK *****
C
C      INDEX = DATA - END INDEXING NUMBER
C      IDENT = PLOT IDENTIFICATION
C      FRASI = SIZE OF MEASURING FRAME , SQ.FT.
C      PREHAR = PRE-HARVEST LOSS , LBS/ACRE
C      TRUCOL = THRU-COMBINE LOSSES , LBS/ACRE
C      PLOTSI = SIZE OF FIELD PLOT , SQ.FT.
C      BINYE = BIN YIELD , ACTUAL PLOT YIELD
C      BINPA = BIN YIELD ,CONV. TO LBS/ACRE
C      SHAPCT = SHATTER (+PREHAR)LOSS IN BEANS/FRAME
C      STAPCT = STALK ,OR CUTTERBAR,LOSS- BEANS/FRAME
C      XLOPCT = LODGED LOSS BEANS/FRAME
C      STUBPF = STUBBLE LOSS BEANS/FRAME
C      SHALPA , ETC = SHATTER LOSS , ETC , LB/A
C      TSHLPA = TRUE SHATTER LOSS , LB/A ,
C      = SHALPA - PREHAR
C      SHABPCT , ETC = SHATTER LOSS , PERCENT
C      OF NET YIELD , ETC
C
1  C      DIMENSION STLPA(5) , XLLPA(5) , STUPA(5) , TSHPA(5)
      $ , THLPA(5) , BNPA(5) , IDFN(5) , STUBLI(5) ,
      $SHPCT(5) , STPCT(5) , STUPC(5) , XLPCT(5) , THPCT(5)
2  50 READ (5,10) INDEX, FRASI , REAPP , PREHAR , TRUCOL,PLOTSI
3  10 FORMAT ( 11 , F9.4 , 4F10.4 )
4  IF ( INDEX .GE. 9 ) GO TO 300
5  WRITE (6 , 100) FRASI , REAPP , PREHAR , TRUCOL , PLOTSI
6  100 FORMAT ( /5X , 'EXPT INPUT DATA',/,5X,5F10.4 )
7  WRITE (6 , 150 )
8  150 FORMAT ( /5X , 'HEADER LOSS DATA EXPRESSED AS PERCENTAGES',
      $/,5X , 'PLOT' ,3X,'SHATTER',2X,'STALK',3X,'LODGED',2X,
      $'STUBBLE' ,3X,'TOTAL' , 2X , 'NET POTL', ' STBL'
      $ , /5X , 'IDENT' ,4X, 'LOSS' ,4X,'LOSS',
      $4X , 'LOSS',4X,'LOSS',3X , 'HDR LOSS' ,2X,' YIELD HT',/,
      $55X,'LB/ACRE', ' INS'//)
9  5 READ (5,20,END=300)IDENT , SHABPF , STABPF , XLOBPF
      $ , STUBPF , BINYE , STUBLI
10 20 FORMAT(1X,I4, F6.1 , 3F10.1 , F12.2 , F9.2 )
11 IF( IDENT. EQ. 0 ) GO TO 50
12 SHALPA = SHABPF * 43560.0 /( FRASI * BEAPP )
13 STALPA = STABPF * 43560.0 /( FRASI * BEAPP )
14 XLOLPA = XLOBPF * 43560.0 /( FRASI * BEAPP )
15 STULPA = STUBPF * 43560.0 /( FRASI * BEAPP )
16 TSHLPA = SHALPA - PREHAR
17 IF ( TSHLPA .LT. 0.0 ) TSHLPA = 0.0
18 TOHLP = TSHLPA + STALPA + XLOLPA + STULPA
19 BINPA = BINYE * 43560.0 / PLOTSI
20 YLDNP = BINPA + TOHLP + TRUCOL
21 SHAPCT = TSHLPA / YLDNP * 100.0
22 STAPCT = STALPA / YLDNP * 100.0
23 STUPCT = STULPA / YLDNP * 100.0
24 XLOPCT = XLOLPA / YLDNP * 100.0
25 THHPCT = TOHLP / YLDNP * 100.0
26 WRITE ( 6,200 ) IDENT ,SHAPCT ,STAPCT ,XLOPCT ,STUPCT
      $ ,THHPCT , YLDNP , STUBLI
27 200 FORMAT (4X,I5, 2X , 4F8.4 , F10.4 , F9.2 , F5.2 )
28 GO TO 5
29 300 STOP
30 END

```

SENTRY

EXPT INPUT DATA

FRASI	BEAPP	PREHAR	TRUCOL	PLOTSI
4.3560	2270.0000	0.0000	80.0000	300.0000

HEADER LOSS DATA EXPRESSED AS PERCENTAGES

PLOT IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE	STBL HT INS
111	1.7003	9.1392	0.0000	4.0383	14.8778	2072.69	7.30
121	2.3008	10.8766	0.0000	1.6733	14.8507	2106.14	6.20
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:

Figure 33. Field header loss data - reduction algorithm.

for the operators. When a data point is missed or erratic, reruns or more replications can be readily conducted; thus, the "gaps" are filled in. The conclusions would be better substantiated.

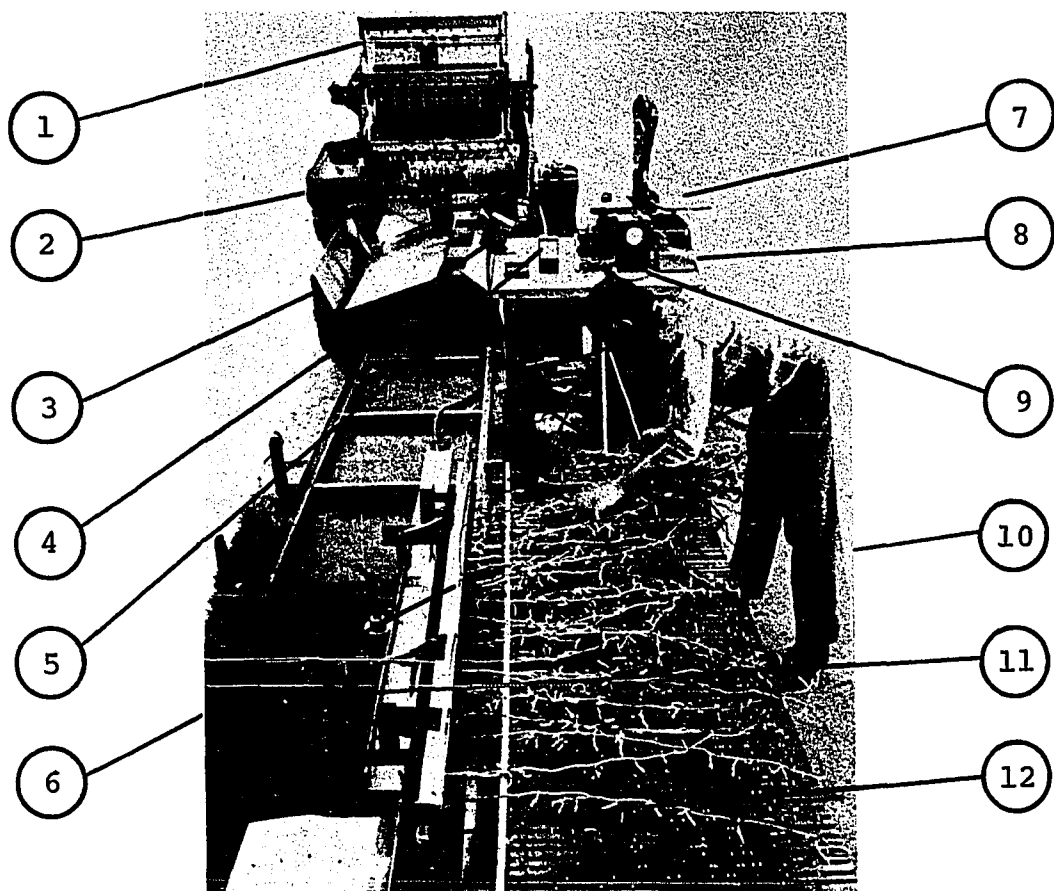
- (5) The possibility of isolation of causes of loss.
- (6) The lab test facility lends itself to the use of high-speed photographic techniques for detailed qualitative and quantitative analysis.
- (7) The pre-testing of improved gathering devices.

The order of priorities in the lab test program were:

- (1) Assess the degree to which lab data could be used to predict field performance and modify the lab equipment to obtain as close an agreement as possible.
- (2) Specify the performance characteristics of the conventional header in detail.
- (3) Test improvements, attachments, and novel gathering mechanisms.

5.6.1 Design of the lab test facility:

Because of the relative bulkiness of the header and the contrasting ease with which crop material could be collected, and because of the desire to use fixed photo-instrumentation gear, the decision was made to move the crop to the header. A Case Model 900 header was cut down to 57 in. width and mounted on a 20 in. high frame attached rigidly to the floor, Figures 34 and 36. A 5-HP electric motor was coupled to a variable-displacement hydraulic pump power supply. The pump stroking lever provided a means for precisely varying the speed of the Char-lynn hydraulic motor that powered the drive side of the cut-down header,



- | | |
|--|--|
| 1. 5 ft Header | 7. Weigh Balances, Toledo
0-500 gm, & Mettler K7T |
| 2. Crop Collection | 8. Delmhorst G-6 Moisture Meter |
| 3. Loss Collection | 9. Standard Millisecond Event
Timer |
| 4. Carriage Speed Control | 10. 3 ft. Gage Track, 40 ft long |
| 5. Carriage Speed Indicator
Zero - Max 0-1000 fpm | 11. Variable Speed Plant Carriage |
| 6. Tilting Plant Clamp | 12. Loading Platform and Guide |

Figure 34. Overall view of lab header test facility, showing pertinent instrumentation.

Figure 35, right.

A 3-ft gauge track, 40 ft long, guided the 4 wheel-drive crop carriage, as constructed by Lalor (37). Speed control over the range 1 to 5 mph was achieved by means of a solid state electric speed control to the 3/4-HP universal motor. Other speed ranges were possible by changing the chain drive ratio to the wheels. Rate of advance of the carriage was checked on each run by an electrical tach-generator and this in turn was periodically calibrated by use of a "Standard" Millisecond Electric Timer, activated by the passage of a carriage wheel over timing switches spaced 4 ft apart. To minimize the accelerating and stopping distance of the cart, a coating of epoxy-resin paint and carborundum powder was applied to the tracks. The control circuit acted as a brake when the drive direction was reversed.

Cutting height was adjustable from 2 in. to 6 in. by adjustment of the slotted mounts anchoring the base of the crop clamp. A simulated single row up to 5 ft long could be clamped between the 2 x 2 in. aluminum angles.

Tests were standardized by loading a row length of about 4 ft of plants into the clamp. This loading produced component losses sufficient to indicate at least 100 times the least scale division (0.02 g) on a Mettler Type K7T 800 g balance.

The crop clamping force was critical. Excessive clamping pressure crushed the plants and led to stem breakage. If the clamping force was too low, on the other hand, the plants tilted forward and pulled out during cutting and crowding at the knife, and stubble length was

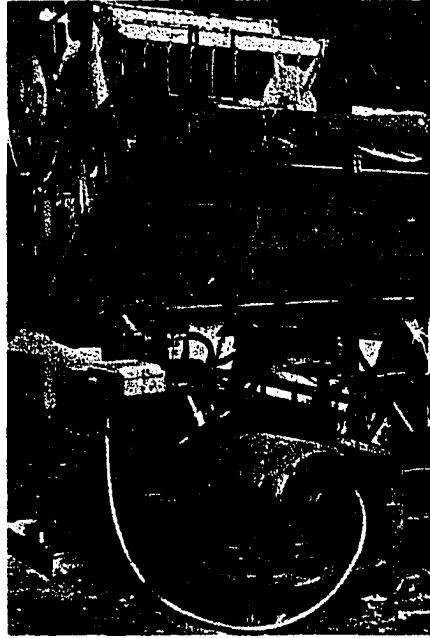
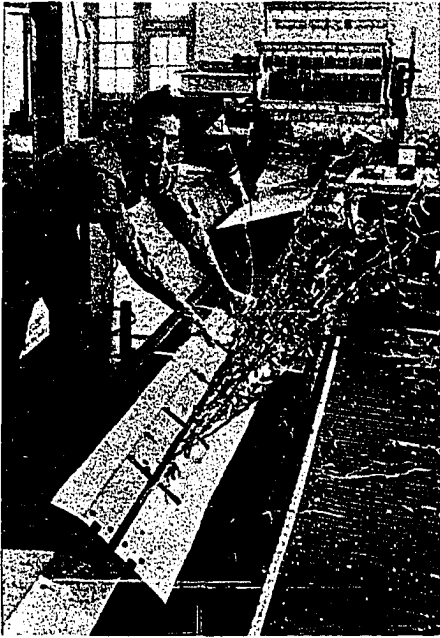


Figure 35. Left, tilting plants in clamp into operating position.
Right, rear view of variable speed hydraulic drive for header.

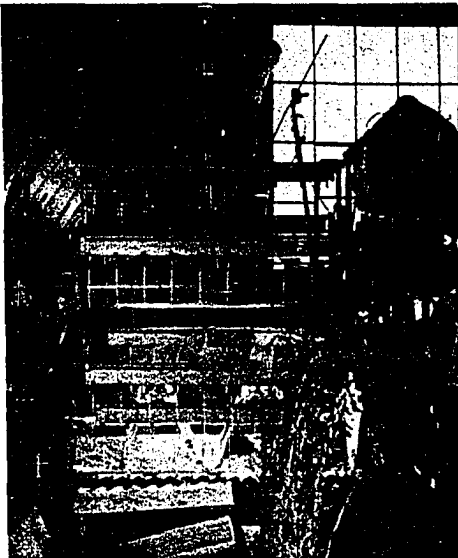


Figure 36. High speed photographic measurements.
Left, HYCAM movie camera being readied for overhead shot, note centerless auger.
Right, stroboscopic still photograph of a single stem being cut. Rate of advance - 700 fpm, 50 pps.

exaggerated. To reduce the intensity of the clamping force, rubber weatherstrip was glued to each side of the clamping plates. Satisfactory results were obtained when a force of about 30 lb. was required to pull 1/4 in. diameter stems out of the clamp, i.e. about 70% of the force required to uproot the plant in the field.

Plants used for lab tests were pulled from the field, roots and all, shaken free of dirt, and stored. When required for tests, they were inserted in the clamp at "ground level." In the absence of a conditioning cabinet, MC was difficult to control.

The clamp was loaded with plants spaced as they would be spaced in the field. Spacing of variety Amsoy, for example, was normally 6 to 8 plants per foot when grown in 30 in. rows. The loading platform was an horizontal board with milled slots that provided a spacing guide. After the plants were inserted, the clamps were closed on them and locked by toggle-grips. The loaded clamp was then swung into the vertical position on the carriage, Figure 35, left.

As the carriage and the crop passed under the header, the bean losses were deflected into the two 8 ft troughs, one located on each side of the track, and then collected in trays before inspection, sorting and weighing. Standardized data sheets facilitated the recording of data. The remaining crop material collected from the header platform was threshed out by stationary thresher or by hand and represented "bin yield." Bin yield was measured on a Toledo 500 g scale.

Usually more than four replicates were run for each machine setting, depending on the nature of the experiment. To obtain a limited degree of control on crop moisture content (an important variable in the tests), the

plants were stored in a cool place, or wetted, then brought into the lab where they dried down to the required moisture content. Plants kept indoors for several days would ultimately achieve their equilibrium MC, which could be as low as 7% seed moisture, depending on ambient atmospheric conditions.

5.6.2 Initial problems in operation:

The stubble profile was of importance. To preserve the oncoming stubble, it was found necessary to cut away the structural member under the cutterbar to minimize interference. Stubble losses and height were checked when the carriage was at the far end of the track.

In the single-row lab situation, any adverse characteristics of the platform auger were exaggerated. Without the adjacent rows feeding into the header, many plants tended to be thrust back by the auger. In the field this tendency is diminished by interaction with adjacent plant rows. The problem was minimized in the lab, without detriment to the results, by enshrouding the auger to form a trough on the feeding end of the platform.

The last plants in the row occasionally tended to fall out of the header, but continuity could be maintained by taping the last few plants above cutting level to those ahead of them on the carriage.

5.7 Field and Lab Testing Compared

Regression analyses on the data from 1969 and 1970 field trials and parallel tests in the lab resulted in variances that did not differ significantly between field and lab data. Lab test variances, however, were not reduced below those of the field trials, as was expected, but field and lab characteristic curves were similar.

An attempt was made in 1970 to run a header loss vs. variety comparison between lab and field. Three varieties with differing genotypic characteristics were harvested; namely, Amsoy, Hawkeye, and Corsoy.

Unfortunately, poor weather adversely affected the parallelism of the test in that season, since the field beans were up to 19.3% MC when harvested late. When the field data were adjusted according to the header loss vs. moisture relationship (see section 6.3), reasonable consistency was found between lab and field results. Using this data and the results of a reel index trial, the lab data was regressed on moisture-adjusted field data, Figure 37, and resulted in a correlation coefficient $r = 0.96$ (data in Table A-6).

The field data deviated increasingly from the lab results as the magnitude of losses increased (quadratic term was not significant). Probable reasons for the increasing disparity of the field results were:

1. Plant lodging and weeds found in the field situation.
2. Repeated handling of the plants pulled from the field knocked out partially-dehiscid beans or weak pods before lab testing.

At low loss-levels, on the other hand, the lab results might tend to be higher because it was possible to locate all the lost beans in the trial in the lab.

Branches are a primary source of stalk loss at the cutterbar. In a brief test involving the removal of the major branches from the plants for lab tests, the results for branchless plants showed less variance. Yield was depressed by 20%, but header loss was reduced overall by 25%.

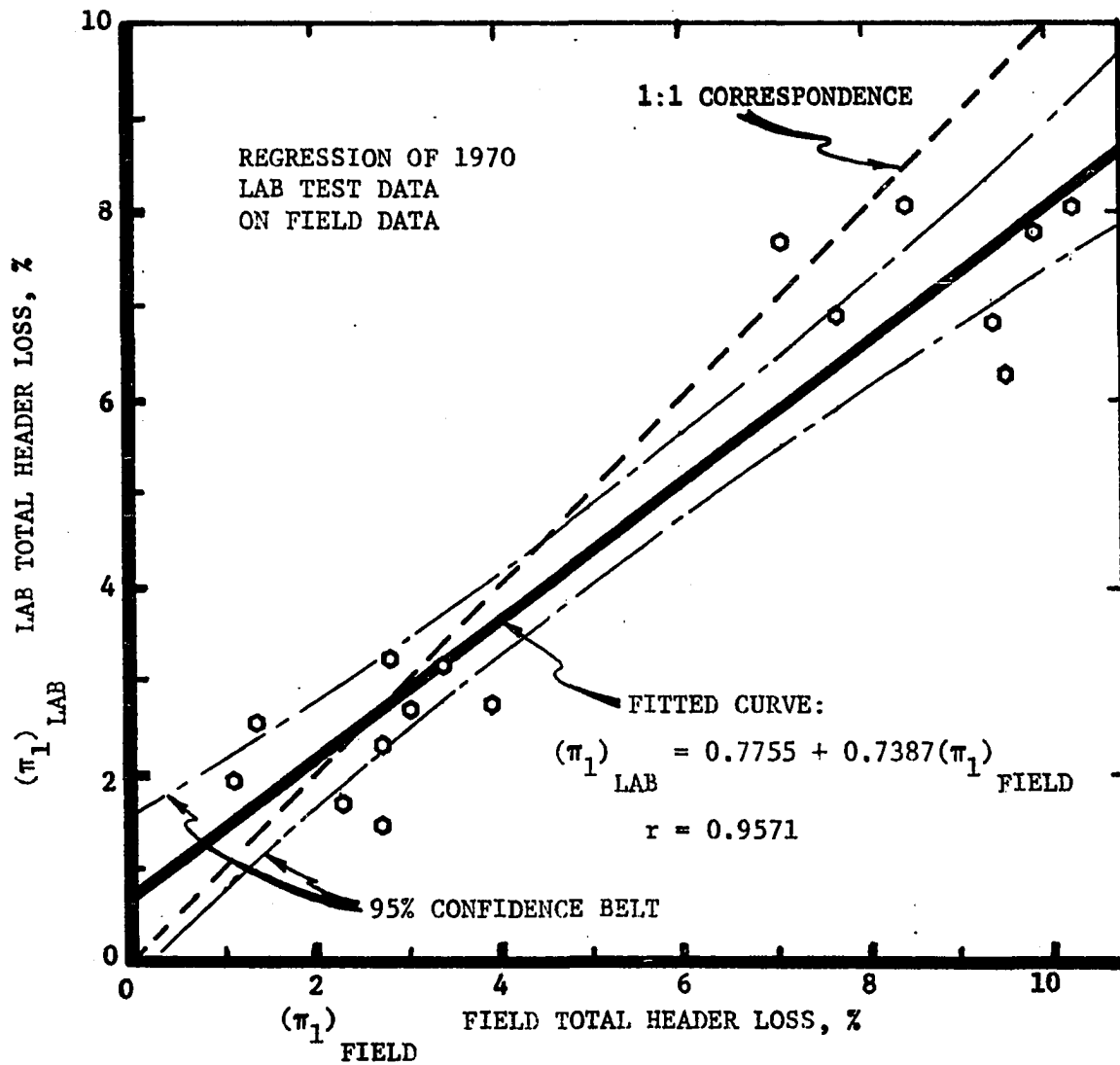


Figure 37. Linear regression of lab test header loss on field test results, three-variety and reel index trials, 1970.

5.7.1 Comparative costs of data collection between lab and field:

Lab testing enabled a high degree of control over the machine variables. The tests could be readily planned and conducted whenever necessary, with minimum of supervision of those assisting with the data collection.

A considerable overall reduction in the expense of data collection was effected, as indicated in Table 16.

Table 16. Comparison between lab and field^a header loss data - collection time, labor^b and costs.

	Time per test run, min/man	Minimum labor required, men	Average hr wages dollars/man	Estimated cost, dollars per test point
Field	10	4	2.40	5.60
Lab	18.5	2	2.00 ^b	2.46

^aIncludes all activities required for the collection of data after the crop has reached maturity in the field.

^bThe supervision of the researcher was not constantly required in the lab as it was in the field.

5.7.2 Summary - lab and field testing compared:

Most of the advantages anticipated of the lab test facility were realized in practice. Over 1,000 lab test runs were made. The cost of collecting data was less than half that in the field. The characteristics of the standard header were observed over a continuous spectrum of performance variables in a way not readily achievable in the field.

The data was obtained in comparative comfort and independently of the weather, or the need for seasonal timing.

5.8 Presentation of Characteristic Equations

One objective of the analysis of the standard header was to determine probabilistic or semi-empirical relationships between the response variables and the independent variables. The functional forms chosen must be technically feasible and manageable in size.

As an example, consider the lab studies on header component-influences on header loss. Initially, the data from individual tests were fitted by least-squares multiple regression to estimate the five coefficients in a model of the form

$$\hat{\pi}_1 = \frac{\hat{A}}{X_1^2} + \frac{\hat{B}}{X_1} + \hat{C} + \hat{D}X_1 + \hat{E}X_1^2 \quad (5-7)$$

Stepwise regression methods which converge to a unique model do not guarantee that the model is the most functional (73). Partial sampling of the 31 ($2^f - 1$, where $f = 5$) possible equations by using the Mallows' C_p statistic (22) was preferred instead, so that as few coefficients as possible might be retained and models of similar effectiveness compared.

The C_p statistic, related to total error of predicted values $\hat{\pi}_1$ for all n data points was defined as

$$C_p = \frac{\text{Residual sum of squares}}{s_f^2} - (n-2p) \quad (5-8)$$

where:

s_f^2 = residual mean square from the equation containing the full set of coefficients,

p = number of coefficients fitted from the set (22).

The equation with coefficients giving the lowest $|C_p - p|$ becomes the best

candidate for interpretation purposes. That a search does not lead to a single equation emphasizes the limitations of the data.

In certain instances, as for the bean loss vs. cutting height relationship of Figure 23, an exponential function of the following form was considered more appropriate:

$$\hat{y} = \hat{A} e^{\hat{b}x}, \quad (5-9)$$

and an OMNITAB regression program was modified accordingly (see Table A-7).

Only the Total Header Loss equations, with their estimated coefficients, coefficient of determination, R^2 (73), and standard deviation, $s_{y/x}$, are detailed in the body of this work. Other information is tabulated in the Appendix. The stated coefficients were normally chosen when significant at the 1% level. Fitted curves for Total Header Loss do not necessarily represent the sum of the individual component - loss curves plotted, as these were fitted individually.

Where a test was conducted in the lab, it will be so indicated.

5.9 High-Speed Photographic Instrumentation

The header lab facility provided better control over most of the variables involved than field tests. Some of the rapidly occurring and complex plant-machine interactions were selected for study by means of high-speed photo-instrumentation.

Film can be used in analysis to aid the eye by overcoming its limitations of time, distance, illumination and memory. But one of the most important attributes of the photographic method in scientific data acquisition rests in the fact that the camera as information recorder

rarely loads the phenomenon under investigation, nor significantly disturbs its normal behavior. Often, it is the least expensive and easiest means of data acquisition. No other system can compete for speed of recording quantities of data. Information recording rates of 10^{15} bits per second are possible. Although the data can be readily amassed and the data-handling problem shelved till later, there is an unfavorable transformation between recording rate and readout rate, and much of the information on the film may be irrelevant (62).

The film constitutes a permanent record which can be re-examined as often as needed, by a number of observers, and can be analyzed both quantitatively and qualitatively.

Two high-speed photographic techniques, i.e. requiring film exposure times shorter than that provided by the fastest mechanical shutters (32), were used extensively for data analysis and documentation in this study:

- (1) the continuous film-transport movie camera with rotary prism optical compensation, and a data-analyst projector
- (2) "stroboscopic" still photography.

Results were corroborated in the field by the use of the intermittent film transport movie camera, operated up to 64 pictures per second (pps).

5.9.1 High speed Cine-camera Techniques:

For data reduction from movie film records, the maximum recordable subject velocity depends upon the degree of image blurring that can be tolerated. Blurring should be reduced to a point where it does not exceed the diameter of the circle of confusion. This is the largest sized disc which appears as a point when the projected image or print is viewed under

normal conditions. Usually the exposure should be such that the fastest element to be analyzed would not move more than is represented by about 1/500th of an inch on the image plane of the camera. Image spatial resolution (blur) depends upon:

V = transverse component of subject velocity, in./sec

M = image magnification

t = actual exposure duration, sec

θ = angle between plane of motion and the film plane, degrees

$$\text{i.e. image blur (in.)} = t M V \cos \theta \quad (5-10)$$

The requirements for good temporal resolution, i.e. shortest exposure times, fast, coarse-grained film, high f-stop, are in conflict with those for good spatial resolution. The resolving power of the camera and projector optics can be estimated by the use of a standard Optical Test Target. A resolution of 56 lines/mm was known to be the limit for the high-speed panchromatic film emulsion. See Figure 68C.

A Redlakes HYCAM K 2004 E camera, with 11,000 full frames per second capacity, was available from the ISU Film Production Unit. This camera has a disc shutter in optical series with the rotating prism, which limits film exposure duration to some fraction of prism rotation, for better motion-stopping performance, i.e.

$$t = \frac{\beta}{360 \text{ (pps)}} \quad (5-11)$$

For the standard shutter $\beta = 144^\circ$, and at a 10,000 pps taking rate, $t = 40$ microsec. With the special narrow-aperture shutter $\beta = 9^\circ$, and at 10,000 pps, $t = 2.5$ microsec. Figure 68C shows the HYCAM with standard

shutter being focused on a Patterson Optical Test Target in preparation for filming the impact cutting phenomenon. Tungsten flood lighting (12 kw) was used and Kodak 4-X negative film (ASA 400) developed commercially. Spatial resolution was found to be somewhat above 10 lines/mm, i.e. image blur would be 0.004 in. on the film. The maximum desirable width of field could then be estimated by equating this blur with the quantities in the equation

$$\text{using } M = \frac{\text{film frame width (0.4 in. for 16 mm film)}}{\text{width of field covered by the lens in object plane}}$$

$V_{\max} = 2000 \text{ in./sec}$, the fastest subject motion studied; i.e. the impact cutting of a stem by a blade traveling at 10,000 fpm. By substitution, the effective field width can be determined from

$$\text{Maximum width of field} = \frac{0.4 t V \cos \theta}{\text{image blur}} \quad (5-12)$$

With the standard shutter $t = 40 \text{ microsec}$, and if $\theta = 0.0$;

Maximum width of field = 8.0 in., for the impact-cutting study.

An L-W Model 900 Analyst Stop-Action Projector was used for data-reduction from the film. The images were projected from overhead onto a drafting table so that particle motion could be plotted and analyzed.

5.9.2 Quantitative analysis of film records:

The problem involved the determination of particle or rigid body velocity and acceleration components from the displacement-time record. The method of finite differences and Taylor's series expansion was employed (41) so that a computer program could be written (44) which would

provide the velocity and acceleration of points as functions of time, when tendered the reference coordinates, the particle coordinates and the film elapsed time (or framing rate and frame number).

Referring to Figure 38A, let xyz be a non-inertial coordinate system fixed in the header and XYZ an inertial reference system fixed in earth. The velocity and acceleration of particle P as seen in the XYZ-frame (absolute motion) is related to the velocity and acceleration of particle P in xyz as follows

$$\underline{v}_{XYZ} = \underline{\dot{\rho}} + \underline{\dot{R}} + \underline{\omega} \times \underline{\rho} \quad (5-13)$$

$$\underline{a}_{XYZ} = \underline{a}_{xyz} + \underline{\ddot{R}} + 2 \underline{\omega} \times \underline{\dot{\rho}} + \underline{\omega} \times (\underline{\omega} \times \underline{\rho}) + \underline{\alpha} \times \underline{\rho} \quad (5-14)$$

where

\underline{v}_{XYZ} = velocity of P in XYZ-reference frame

\underline{a}_{XYZ} = acceleration of P in XYZ-reference frame

\underline{v}_{xyz} = velocity of P in xyz-reference frame

\underline{a}_{xyz} = acceleration of P in xyz-reference frame

$\underline{\dot{R}}$ = velocity of origin of xyz in XYZ

$\underline{\ddot{R}}$ = acceleration of origin of xyz in XYZ

$\underline{\omega}$ = angular velocity of xyz in XYZ

$\underline{\alpha}$ = angular acceleration of xyz in XYZ

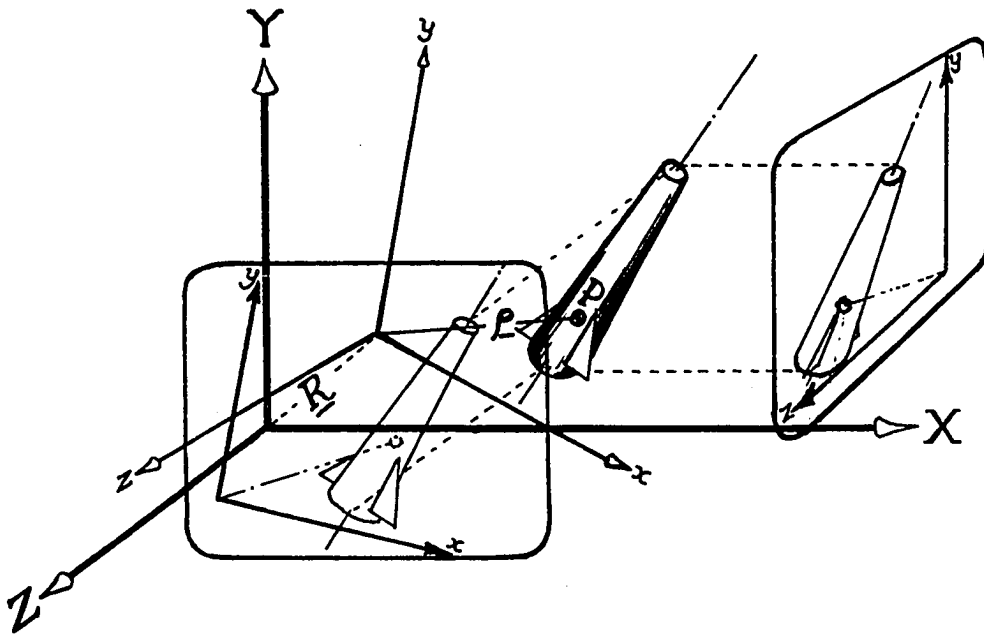
$\underline{\rho}$ = position vector of P in xyz

$\underline{\dot{\rho}}$ = velocity of P in xyz = \underline{v}_{xyz}

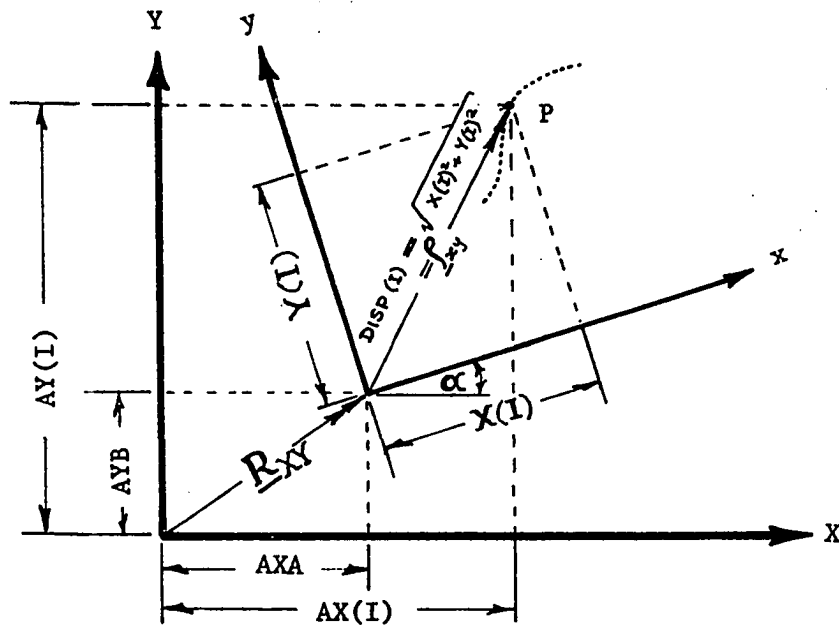
\underline{r} = position vector of P in XYZ

\underline{R} = position vector of origin of xyz in XYZ

For the particle as a system within XYZ



A. Camera and subject relative positions



B. Location of point P in coordinate reference frames

Figure 38. Determination of particle motion.

$$\Sigma \underline{F} = m \underline{a}_{XYZ} \quad (5-15)$$

The following generalizations were made to simplify calculation, see Figure 38B:

1. Since only one camera was available, movement in the Z-plane could not be directly recorded. To use mirrors and a transposed image on the same film, as in Bledsoe (5), would have further reduced the available field width. To measure motion in the Z-plane by geometric projection from measurements of changes in dimensions of the body would be beyond the spatial resolution capability of the system. Changes in attitude in the Z-plane were accordingly ignored, as also were rotations about the longitudinal axis of the body.

2. It was assumed that the subject was far enough away from the camera, parallel with, and centered on, the camera lens-axis so that X- and Y-scale distortions and lens aberrations could be ignored.

3. The header was fixed relative to the camera. Film movement relative to the camera or projector was compensated, when it occurred, by moving the viewing screen so that the xyz origin was maintained in the same position in the field. Thus the following assumptions could be justified:

$$\dot{\underline{R}} = \ddot{\underline{R}} = \underline{\omega} = \underline{\alpha} = 0; \text{ consequently } \Sigma \underline{F} = m \underline{a}_{xyz} \quad (5-16)$$

$$\underline{v}_{XYZ} = \underline{v}_{xyz} \text{ and } \underline{a}_{XYZ} = \underline{a}_{xyz} \quad (5-17)$$

5.9.3 Procedure:

1. Rectify the coordinates, using a projection scale factor (SCF).

The Ith position of the particle within the XYZ-frame (absolute coordinates) is

$$X(I) = [(AX(I) - AXA) \cos \alpha + (AY(I) - AYB) \sin \alpha] \cdot SCF \quad (5-18a)$$

$$Y(I) = [(AY(I) - AYB) \cos \alpha - (AX(I) - AXA) \sin \alpha] \cdot SCF \quad (5-18b)$$

$$DISP(I) = \sqrt{[X(I)]^2 + [Y(I)]^2} \quad (5-18c)$$

where

AXA, AYB = absolute X,Y coordinates of the xyz origin

AX(I), AY(I) = absolute X,Y coordinates of particle P

α = ALPHA = angular displacement of the xyz frame

DISP(I) = Ith resultant displacement of particle P.

2. Employ Taylor's expansion: If a function $X = X(\text{TIME})$ and its derivatives are continuous in the vicinity of the point $X(I)$, then for any value of X close to $X(I)$, or $\underline{X}|_t$, the function may be represented by a Taylor's series:

$$\underline{X}|_{t+\Delta t} = \underline{X}|_t + \Delta t \dot{\underline{X}}|_t + \frac{(\Delta t)^2}{2} \ddot{\underline{X}}|_t + \text{-----} \quad (5-19)$$

and

$$\underline{X}|_{t-\Delta t} = \underline{X}|_t - \Delta t \dot{\underline{X}}|_t + \frac{(\Delta t)^2}{2} \ddot{\underline{X}}|_t + \text{-----} \quad (5-20)$$

Subtracting Equation 5-20 from Equation 5-19 yields

$$XVEL(I) = \dot{X}|_t = \frac{\dot{X}|_{t+\Delta t} - \dot{X}|_{t-\Delta t}}{2 \Delta t} \quad (5-21)$$

and proceed similarly for YVEL(I). The resultant Ith velocity of particle P is

$$VEL(I) = \sqrt{[XVEL(I)]^2 + [YVEL(I)]^2} \quad (5-22)$$

adding Equation 5-19 and Equation 5-20 and re-arranging:

$$XACCEL(I) = \ddot{X}|_t = \frac{\dot{X}|_{t+\Delta t} + \dot{X}|_{t-\Delta t} - 2\dot{X}|_t}{(\Delta t)^2} \quad (5-23)$$

Proceed similarly for YACCEL(I).

The resultant Ith particle acceleration is

$$ACCEL(I) = \sqrt{[XACCEL(I)]^2 + [YACCEL(I)]^2} \quad (5-24)$$

3. Interpolation for the end points: after the first "differentiation" the range of the original interval was reduced by $2\Delta t$, and again upon the second differentiation. Quadratic interpolation was used to supply approximate values for the missing end points, see Table A-10.

In Figure 39 is seen a facsimile of the instructions for the program used to compute, and employ a SIMPLOTTER routine to plot out absolute displacement, velocity and acceleration of a particle.

4. Exercise the program to check for programming and other errors: A calibration sub-routine (program SINCAL) was written, which employed a simple harmonic function and its derivatives

Figure 39. Computer program for the determination of displacement, velocity and acceleration of a particle, when tendered particle coordinates and elapsed time.

$$\underline{x} = \underline{A} \sin \underline{\omega t} \quad (5-25a)$$

$$\dot{\underline{x}} = \underline{A} \underline{\omega} \cos \underline{\omega t} \quad (5-25b)$$

$$\ddot{\underline{x}} = -\underline{A} \underline{\omega}^2 \sin \underline{\omega t} \quad (5-25c)$$

By using a range of values for time t sec, frequency $\underline{\omega}$ rad/sec, and amplitude \underline{A} in., the accuracy of the method of finite differences could be checked, at the same time giving values for the (assumed) sinusoidal motion of a 3 in. stroke reciprocating cutterbar at 500 rpm for time increments of 0.0025 sec.

Using the SINICAL sub-program the maximum errors due to finite differencing were found, by comparison with theoretical values, to be + 0.41% in velocity and + 0.69% in acceleration. The interpolated end-points were ignored in these error determinations.

The briefer the time interval, Δt , theoretically the smaller should be the error by finite differencing. On the other hand, the shorter the time interval, the greater the percentage error in the differences between the measured ordinate and abscissae.

5. Error analysis, using linear error theory:

Differentiation is an "error-magnifying" process. Consider the acceleration equation:

$$\text{ACCEL}(I) = f \left\{ \text{DISPL}(I), [\text{TIME}(I)]^{-2} \right\} \quad (5-26)$$

if $\text{DISPL}(I)$ and $\text{TIME}(I)$ are mathematically and statistically independent, then the propagation of error equation may be used to estimate the probable error in acceleration as follows:

$$\left\{ \frac{W_A}{ACCEL(I)} \right\}^2 = \left\{ \frac{W_D}{DISPL(I)} \right\}^2 + 4 \left\{ \frac{W_T}{TIME(I)} \right\}^2 \quad (5-27)$$

Maximum acceleration error,

$$W_A|_{\text{maximum}} = ACCEL(I)|_{\text{max}} \sqrt{\left\{ \frac{W_D}{DISPL(I)} \right\}^2 + 4 \left\{ \frac{W_T}{TIME(I)} \right\}^2} \quad (5-28)$$

The HYCAM camera timing light (which exposes indexing blips on the side of the film) was checked by the ISU Physics Department and found to measure 1015.8 pps at an indicated 1000 pps, thus the error W_T in $TIME(I)$ was

$$\frac{1015.8 - 1000}{1015.8} \times 100 = +1.56\%.$$

Measurement error (least scale division) was estimated at ± 0.01 in. on a minimum displacement difference of 0.1 in., i.e. $W_D = 10.0\%$. Substituting in Equation 5-28:

$$\text{Estimated acceleration error} = \pm 10.3\%.$$

5.9.4 Sequence-flashing or stroboscopic still photography:

In order to reduce the expense involved in film usage with the HYCAM (for example, a 100 ft roll of film at 10,000 pps required a 300 ft leader and 1.9 sec to accelerate to test speed) and the time delay in film processing (from one to three days), stroboscopic still photography was employed. Two or three General Radio Type 1531 A Strobotacs were triggered simultaneously to illuminate the subject in the darkened lab while the camera lens was held open. All surfaces surrounding the subject were painted matte black and black velvet back drops were used to minimize reflection from all but the subject. Camera settings were approximated

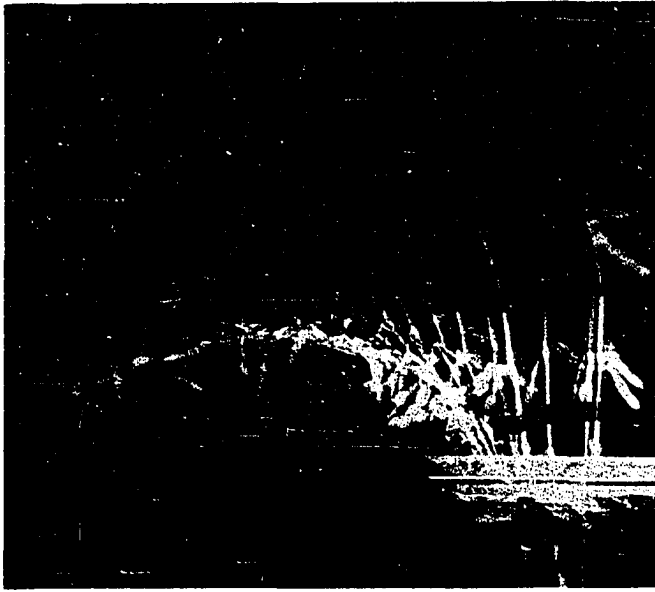
initially by the use of the empirical charts supplied in General Radio handbooks. The precise lens opening was determined by trial and error for each camera/film/stroboflash location/distance combination. Leica and Pentax 35 mm cameras were loaded with Kodak Tri-X film. The film was "pushed" eight stops during development to 3200 ASA for better quality prints. A close similarity was noted between results obtained by the Polaroid 110B camera, with Polaroid Type 47 Land-Pack film (ASA 3000), and the Tri-X film with the faster development. At flashing rates of 100 pps the stroboflash duration was only 0.8 microsecond, hence the need for development compensation with Tri-X film (nominal 400 ASA).

Several important advantages were realized with the stroboflash and still photographic method over high-speed movie analysis for transient motions:

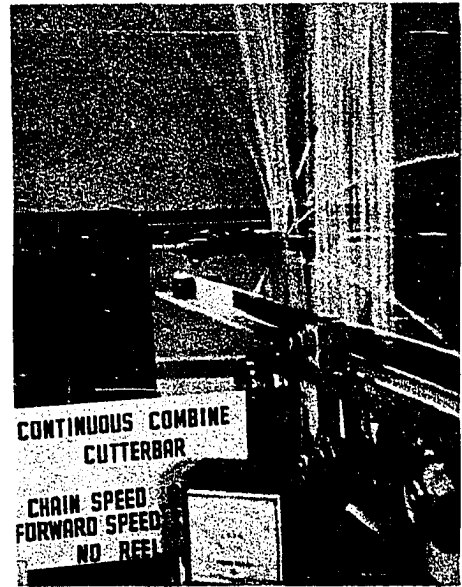
- a) A Polaroid camera and film could be used, allowing immediate developing and rapid zeroing-in on camera and light settings,
- b) All the necessary information on coplanar motion of the subject under a particular set of conditions was recorded on single photographs.

The repetitive flash method was not suitable for cyclic motions.

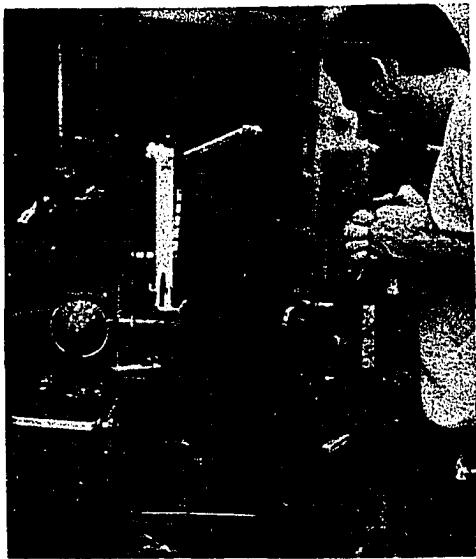
In Figure 40 some of the instrumentation is shown and also two illustrations of the results.



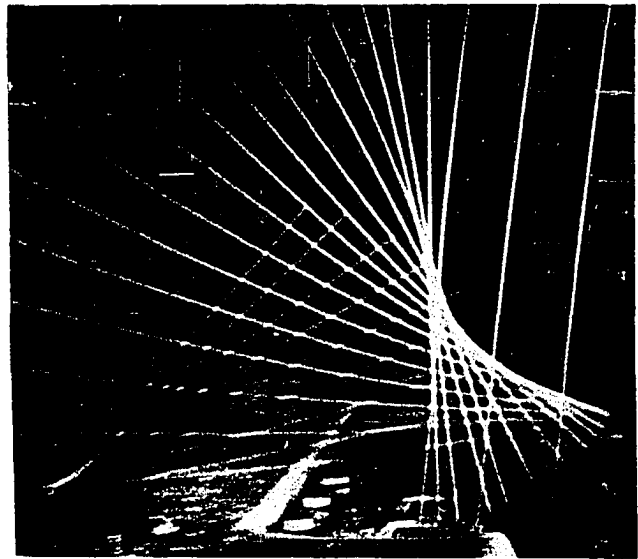
A. Front view of soybean stem being severed. Chain cutterbar speed - 300 fpm, flashing rate 70 pps.



B. Continuous chain cutterbar lab model in action cutting 1/8 in. dowels.



C. Strobotac and camera being readied for pod impact photo.



D. Side view of 1/8 in. dowel being severed.

Figure 40. Stroboscopic (repetitive flash) high-speed still photography.

6. CHARACTERISTICS OF THE STANDARD HEADER

The characteristics of the standard header should be known before an in-depth study into the precise causes of header losses is undertaken. Using the methods of the previous section and a Model 600 Case combine, equipped with a 10-ft header and commercial M & W hydraulic header height control, as the standard machine, the following tests were conducted.

6.1 Header Loss Vs. Speed and Stubble Length -- Field Trial

A two-factor factorial design with four treatment levels and two replications was used to observe the effect of speed and stubble length on header losses. The test was conducted in the 1969 season in variety Amsoy, with the crop in excellent condition. Net potential plot yields ranged from 37.7 to 59.7 bu/acre. Reel index was 1.2 and moisture content varied between 12 and 13%. Since the amount of lodging was low, stalk and lodged losses were categorized together under "stalk loss" in Figure 41. The response surfaces of these graphs were plotted from multiple regression analyses of the data, Table A-9, in which were fitted models of the general form:

$$\hat{\pi}_1 = \beta_0 + \beta_1 V + \beta_{11} V^2 + \beta_2 L_1 + \beta_{22} L_1^2 \quad (6-1)$$

For total header loss the prediction equation was:

$$\begin{aligned} \hat{\pi}_1 = & 10.8316^{**} - 4.2301^{**} V + 1.4109^{**} V^2 \\ & - 1.2997 L_1 + 0.2891 L_1^2 \end{aligned} \quad (6-2)$$

$$S_{\pi_1/V, L_1} = 2.0143\% , R^2 = 0.9691$$

STANDARD CASE 600 OPEN FRONT HEADER LOSS CHARACTERISTICS

VARIETY AMSOY

SEED MOISTURE 12-1/2%

REEL INDEX 1.2

1969 FIELD TRIAL

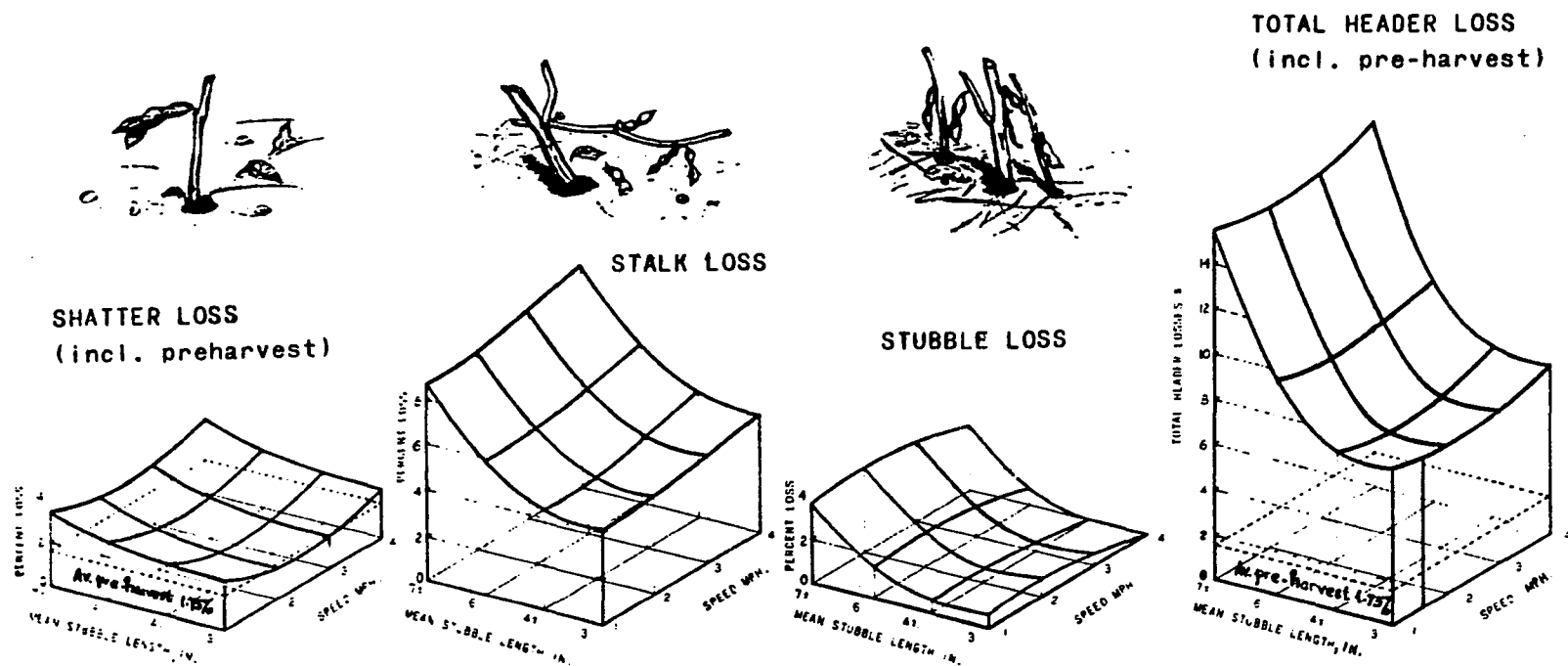


Figure 41. Standard header characteristics. Header loss vs. combine speed and stubble length.

where π_1 = the dependent variable, loss category, %

V = combine speed, range 1 to 4 mph, nominal

L_1 = stubble length, range 3 in. to 7-1/2, nominal

Lowest actual header loss figure was 2.37% of potential yield under best operating conditions (1 mph and 3 in. stubble). Highest header loss was 16.83% at 4 mph with a 7-1/2 in. stubble. The predicted minimum header loss was 4.61% at 1.5 mph and 3 in. stubble length. An interesting problem arose if cutting below 3 in. was attempted; namely, how were losses to be distinguished on a plot which had been bulldozed by the bottom of the header? Fortunately this was a rare occurrence and the problem was avoided by re-running that replication in an adjacent plot space provided for such exigencies.

Combine speed exerted a greater effect on losses in lodged beans than on an erect crop, as will be seen later, in Figure 99 from the 1971 trials.

6.2 Speed Vs. Header Loss -- Lab Test Stand

Since the crop moved to the stationary header and not the header to the crop, the term "rate of advance" was used in place of "forward speed" for the lab tests. Cutting height was precisely controlled in the lab and in this instance the carriage was set for a 4 in. cutting height and the reel index at 1.25, Table A-10.

The regression equation for the curve of Total Header Loss π_1 vs. Rate of Advance, V in Figure 42 was

$$\hat{\pi}_1 = \frac{4.1956}{V} + 2.4779 + 1.1275 V \quad (6-3)$$

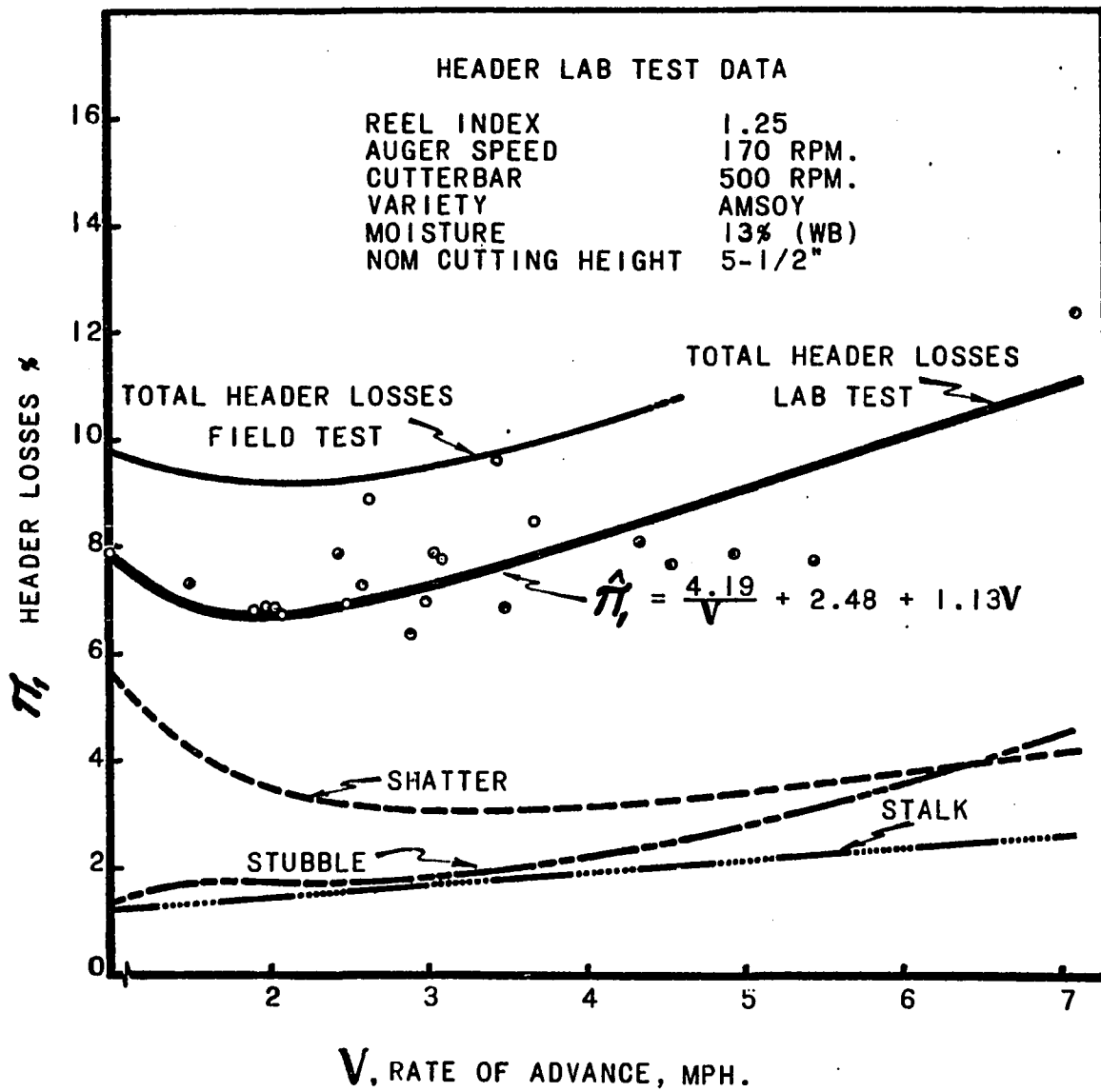


Figure 42. Influence of forward speed on header losses, lab test.

$$S_{\pi_{1/V}} = 0.4143\%, R^2 = 0.9934 \text{ and } V \text{ is in mph.}$$

Minimum loss occurred at 1.93 mph, and the results of a trial in the same variety of soybeans in the field are also reproduced from the previously plotted data in Figure 41.

The rising shatter loss at the lowest speeds accounted for the tendency for header loss to minimize around 2 mph. An explanation for this rise in header loss at very low speeds may be found in a consideration of cutterbar feed rate and plant spacing down the row:

The cutterbar advances 1.1 in. per stroke, at the standard cutterbar speed of 500 rpm (1,000 strokes/min) and at a machine speed of 1.5 mph. If the plants are spaced apart any distance greater than this, then stems will be separated from adjacent stems as the cutterbar has the time to cut them individually. The action of pulling apart interlocking pods, stems and branches leads to increased shatter at the lowest feed rates.

At high forward speeds, or with close plant spacings, stems are bunched or crowded together at the ledger. In the extreme, the standard reciprocating cutterbar can become overcrowded with stalks. Excessive stalk slippage or plugging may occur. The upper limit on combine speed in field operation in soybeans is usually governed by the cutterbar. The speed at which plugging occurs depends primarily upon the crop density and degree of lodging, and to a certain extent, on soil moisture. When soil is wet, stems may be uprooted by the cutterbar and plugging follows as soil and plants mound up at the header. In the 1971 season, lodging and soft ground combined to limit the machine to approximately 3 mph when the

height controller was adjusted for less than a 4 in. stubble.

Under better field conditions, higher speeds and capacity were attained at the price of a longer stubble and higher header losses.

6.3 Crop Moisture Content Vs. Header Loss

A series of runs was undertaken in the header lab using Amsoy bean bundles that had been stored in strategic locations in order to condition them to a range of moisture contents (seed moisture was used as the moisture criterion).

Referring to Figure 43, computed and plotted from the data in Table A-11, it is seen that shatter was the loss most affected by MC. The reason for the diminution in stubble loss at the lower MC was probably because extremely dry pods on the remaining stubble were shattered open during passage under the header and was not due to the cutting action on the stem, as will be seen later. The rising stalk loss at decreasing moisture contents could be due to the increasing brittleness of the stem and branches, which tended to be more readily broken off at lower moisture contents.

This information underscored the need to operate the combine in the field during those parts of the day and season when MC was highest, consistent with seed maturity, stem moisture, and acceptable cylinder damage levels.

The regression equation for Total Header Loss π_1 on MC was:

$$\hat{\pi}_1 = \frac{416.4636}{MC^2} + \frac{19.4411}{MC} + 4.2565 \quad (6-4)$$

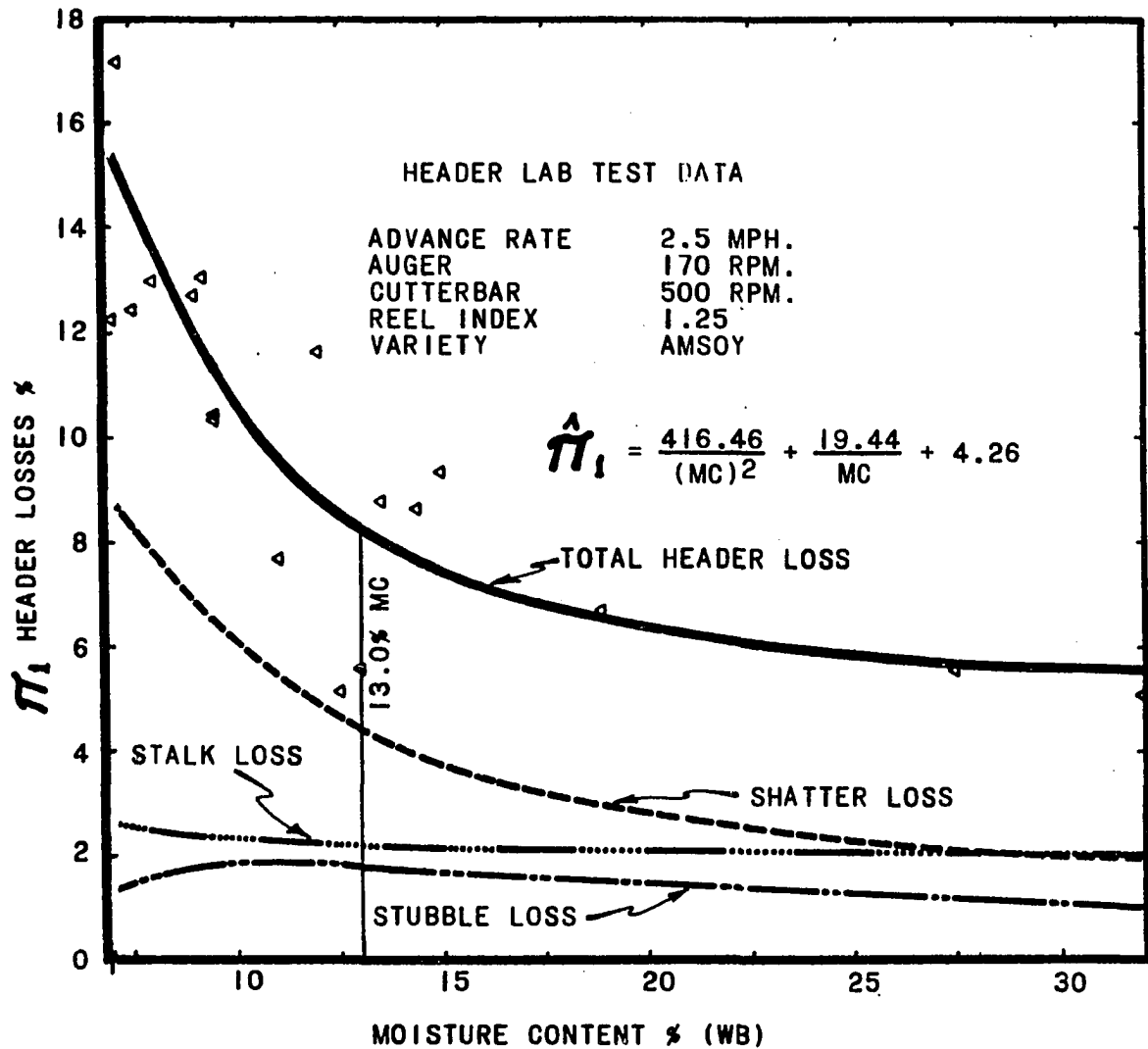


Figure 43. Influence of moisture content on header losses.

$$S_{\pi_{1/MC}} = 0.7962\% \quad R^2 = 0.9678$$

6.4 Influence of Field Practices on Header Loss with the Standard Header

6.4.1 Row spacing:

Narrow row spacing is a key factor in achieving top production levels and aids in significantly reducing header losses at harvest time:

Table 17. Row spacing -- influence on header losses.^a

Row spacing ^b in.	<u>Av. header losses as % of total yield</u>				Total yield bu/acre
	Shatter	Stalk and lodged	Stubble	Total header loss	
	%	%	%	%	
10	1.34	2.39	0.86	4.59	48.73
20	1.46	3.08	1.35	5.89	46.34
30	1.52	2.86	1.36	5.94	40.64
Conclusions	n.s.d.	**	*	**	**

^aSame test as described in Table 10. A Case 960 combine was equipped with 13-ft header and Noble electro-hydraulic automatic height control. Speed, 3.0 mph, reel index 1.25, nominal cutting height 4 in. machine settings.

^bVariety Hark, 15.2% moisture content. Crop was in excellent condition, with practically no lodging and low pre-harvest loss.

Total yield was 19.90% higher on the 10 in. rows than on the standard 30 in. row spacing, while total header loss was 22.72% lower. The differences in both cases were highly significant (at the 1% level). Plants in the 10 in. row spacing podded higher and had less branches --

important factors in lowering header loss. This test was conducted early in the season with the bean moisture at a high level after rains. The cylinder had to be speeded up from the usual 550 rpm to 700 rpm. The consistently low header losses reflected the advantages of harvesting early and at the higher moisture levels.

6.4.2 Influence of weed infestation:

The standard Case 600 combine was operated at 2.3 mph in a controlled weed infestation trial. The weedy plots were infested primarily with foxtail (Setaria faberi) at an average 2.3 plants/ft². The data is found in Table A-12 and summarized below.

Table 18. Effect of weeds on header losses and soybean yield in variety Amsoy at two levels of MC.^a

Treat- ments ^b	MC %	Av. header losses as % of net potential yield				Net potential yield bu/acre
		Shatter	Stalk & lodged	Stubble	Total	
Weedy ^c	16	0.85	0.89	0.10	1.84	36.35
	13.5	0.92	2.93	0.48	4.33	35.85
Weed- free	16	2.87	4.25	1.19	8.31	41.86
	13.5	2.25	4.18	1.91	8.34	50.94

^aOverall differences between moisture levels were not significant at the 10% level.

^bTwo-way analysis of variance on trial means. Treatments: Weeds (two levels), MC (two levels); four replications, two sub-samples per plot.

^cWeed comparisons: Differences highly significant (at the 1% level) on shatter, stalk and lodged, total loss and yield. Differences on stubble loss not significant. Moisture contents x weeds interaction was found not significant at the 10% level.

Header loss was reduced by 62.9% in the weedy plots, a highly significant difference. Weeds tended to reduce header loss due to the tendency for plants in weedy plots to grow taller with wider internodal spacing and less branching than in the weed-free plots. The weeds supported the plants, reducing lodging, and helped the crop to flow more smoothly onto the platform by restricting plant movements during cutting.

Weeds reduced overall yield by 22.2% (10.3 bu), a highly significant difference. Weeds contributed to through-combine losses by:

- (1) raising net moisture content of the cylinder feed, unless harvesting could be delayed until weeds were desiccated by frosts, in which case soybean yield would have been diminished by the delay, due to lower seed moisture, increased natural loss, and increased risk of weather holdups
- (2) reducing threshing efficiency by dampening cylinder impacts on stalks and pods
- (3) obstructing the passage of seeds through the walkers and sieves.

Weeds tended to add foreign material to the bin sample, and lowered market quality.

6.4.3 Effect of ground surface on header losses:

The standard mechanical weed control practices at the AERC field trial locations usually resulted in hills two to four in. high around the bases of the plants in the 30 in. rows. By employing other chemical and mechanical weed control methods, a relatively flat plot surface was obtained for a test comparison. The standard Case 600 combine with hydraulic header height control was operated at an average 2.3 mph in the trial:

Table 19. Effect of cultivation on header loss etc., standard ("hilled") cultivation vs. "flat" land preparation, variety Amsoy, 1969.

	Hilled	Flat
Av. furrow to ridge height, in.	3.75	2.5
Av. height under lowest pod, in.	4.75 (1.5 to 7.0)	5.70 (3.5 to 7.5)
Av. plant height, in.	37.1 (30 to 45)	37.5 (32 to 45.5)
Net potential yield, bu/acre ^a	42.13	35.80
Total header loss, % ^b	9.99	8.57
Av. stubble length, in. ^b	3.81	3.95

^aNet potential yield difference was significant at the 5% level. There was a slight weed infestation in the flat land plots which had a 15.0% lower yield and 14.2% lower total header loss.

^bNo significant difference (at the 10% level) was detected between header losses, or stubble lengths.

It was observed that the higher the ridges, the greater was the tendency for one of the combine wheels to ride up on a ridge and tilt the header, Figure 63.

6.5 Lab Test Enables Component Loss Analysis

There has been speculation in some quarters as to the relative influence on header losses of the individual header components. The Illinois group (49) had concluded that the auger was the prime cause of losses, while the Ohio investigators singled out the reel (10, 38). The lab test stand was accordingly utilized to analyze the contribution to losses of the reel, auger, and cutterbar.

Having found that the standard header would not function at low speeds without a reel or similar device, a substitute "shatter-free" reel, consisting of two air nozzle lifters (using 80 psi shop air pressure) and a centrifugal fan was devised, Figure 53, left. After some adaptation, the arrangement capably performed the job of the reel, yet did not physically contact the plants.

Operation of the complete header with the fan and air nozzles running as well resulted in reducing total header loss by approximately 20%.

Elimination of the auger did not pose any crop-feeding difficulties on the lab test stand in the single row situation.

To determine the loss contribution of the cutterbar, the machine was operated without reel or auger, but with the nozzles and fan running. As a check on the results, cutterbar loss was confirmed (with a reasonable degree of accuracy) by subtracting reel and auger effects from the total.

6.6 Summary - the Standard Header

The speed range for least losses with the standard header in erect Amsoys was 1.5 to 2.0 mph. Increasing speed increased capacity, at the expense of higher header loss and longer stubbles.

Weeds reduced header loss but depressed yield substantially. "Flat" land preparation practices, while not lowering header loss significantly (at the 10% level), did make it easier for the operator to harvest lodged plants, and reduced the adverse effect of header tilting due to one of the combine wheels riding on the ridge. But the most important management factor for higher yields and lower header losses was the selection of narrower row spacing. Narrow row spacing considerably enhanced productive

Table 20. Summary of results of lab trials to determine contribution to total header loss due to reel, auger, and cutterbar. Averages of all runs at two moisture levels (8 & 13%), operating the header test stand both with and without fan and nozzles, in variety Amsoy. Reel index - 1.25, nominal cutting height - 4 in., auger speed - 170 rpm, cutterbar speed - 500 rpm.

Loss category	Header component	Percent due to header component
<u>Shatter loss</u> - fraction due to:	Reel	12.1
(61.2% of mean total header loss)	Auger	12.9
	Cutterbar	75.0
<u>Stalk loss</u> - fraction due to:	Reel	15.4
(21.0% of mean total header loss)	Auger	22.7
	Cutterbar	61.9
<u>Stubble loss</u> - practically all of this loss was attributable to the cutterbar		
(17.8% of mean total header loss)		
<u>Total header loss</u> - fraction due to:	Reel	7.6
(Mean total header loss was 8.18% of total yield)	Auger	12.8
	Cutterbar	79.6

efficiency by its effect on 1) podding height, 2) lodging, 3) extent of branching, and 4) by increasing yield.

Harvest efficiency was higher when harvesting began during those parts of the season and day when MC was higher, consistent with efficient operation of the threshing and cleaning sections.

Isolation of header component losses in the lab indicted the cutterbar as chief contributor to header loss, and it is this mechanism which should be receiving the most attention in an attempt to reduce losses.

7. HEADER COMPONENT ANALYSIS, EVALUATION AND RE-DESIGN

7.1 Row Dividers and Crop Lifters

The first component of the header to contact the crop is the outer row divider. The functions of the divider are to (1) gently clear a path for the appendages on the sides of the header, (2) protect plants in adjacent rows from interaction with the drives and prevent wrapping on the sides of the reel, (3) help lift plants into the cutterbar.

In a severely lodged crop, extended dividers of the Bethard type illustrated in Figure 59 were found to facilitate header operation. These dividers, which are hinged and float on the ground, extended a further three ft beyond the standard fixed dividers they replaced.

Crop lifters are optional attachments available for all combines and are usually necessary on rough ground or in any severely lodged crop. Under bad seasonal conditions lifters may make the difference between a total loss and the salvaging of a valuable proportion of the crop. Two crop lifter designs, one flexible, the other hinged and floating, were illustrated within Figure 6. The mounting brackets of hinged lifters tend to obstruct low cutterbar operation, so that crop lifters are not used in soybeans under favorable harvesting conditions.

7.2 The Reel

The standard header would not gather the crop at low speeds without a reel. The functions of the reel are:

1. to feed the plants to the cutterbar
2. to raise lodged and leaning stems for cutting and collection
3. to rake or sweep the plants over the cutterbar and lay them

on the platform

4. To provide a barrier (either directly by means of the reel bat or bar, or indirectly through plant perturbations) to prevent stems from being bent forward and sliding under the advancing cutterbar. By the same means the reel should prevent severed stems from being thrust out of the platform.

The original bat reel concept is still widely used, but is generally unsuitable for soybeans, and causes higher losses than modern alternative reels in some other crops.

Park reported that in the harvesting of small seeds the use of the tined pickup reel resulted in increases of yield up to 7% more than the same combine equipped with a bat reel (53). Goss et al., working in barley with a 12 ft SP combine, showed a useful reduction in header losses with the pickup reel, and demonstrated the importance of correct reel positioning (23).

Lab tests on variety Amsoy indicated only slightly lower header loss with the pickup reel (primarily due to reduction in stalk and stubble losses), see Tables 21 and 22.

Table 21. Comparison^a between a bat reel and a standard pickup reel in a lab test in variety Amsoy, 10% MC. Both reels 42-1/2 in. diameter, with six reel bars. Rate of advance 2.5 mph; averages stated for two reel indices, 1.5 and 2.0^b.

Reel	Average header losses, percent			Total
	Shatter	Stalk	Stubble	
Bat	2.03	1.88	0.87	4.78
Pickup	2.48	1.24	0.41	4.14
Conclusions	Diff. sig. at 10% level	n.s.d.	*	n.s.d.

^aTwo-way analysis of variance, four replications of each of the two treatments (reels) at two levels (reel indices).

^bDifferences between reel index settings not significant.

Table 22. Comparison^a between a bat reel and a standard pickup reel in a lab test in variety Amsoy, 10% MC, at two reel height settings^b. Rate of advance 2.5 mph, reel index 1.5. Both reels 42-1/2 in. diameter, with six reel bars.

Reel	Average header losses, percent			Total
	Shatter	Stalk	Stubble	
Bat	2.37	2.53	0.85	5.75
Pickup	2.50	1.42	0.45	4.37
Conclusions	-- ^b	Diff. sig. at 10% level	Diff. sig. at 10% level	n.s.d.

^aTwo-way analysis of variance, four replications of each of the two treatments (reels) at two levels (heights).

^bLoss differences between reel height settings (5 & 12 in.) was not significant, except in shatter loss. The higher reel setting resulted in higher shatter loss due to increased stalk slippage at the cutterbar.

The deeper penetration of the tines on the pickup reel led to better control over the plants at the cutterbar, but with slightly higher shatter loss than the bat reel. These results pertain to the lab conditions in an erect crop. In lodged and tangled crops, the bat reel becomes less effective and the use of the tined pickup reel is considered mandatory, Figure 44. The pickup reel tines enter vertically and retain that orientation and, according to Park, result in a smoother flow of material to the header, superior cutting and less slugging at the cylinder (53).

The undesirable manner in which the bat reel enters a tall crop is illustrated in Figure 45, left.

The first U.S. patent on a pickup reel design was granted to Schueler, Figure 47. This patent disclosed a cam action similar to that used on hay harvesting equipment today (68). Combine reels generally accomplish their

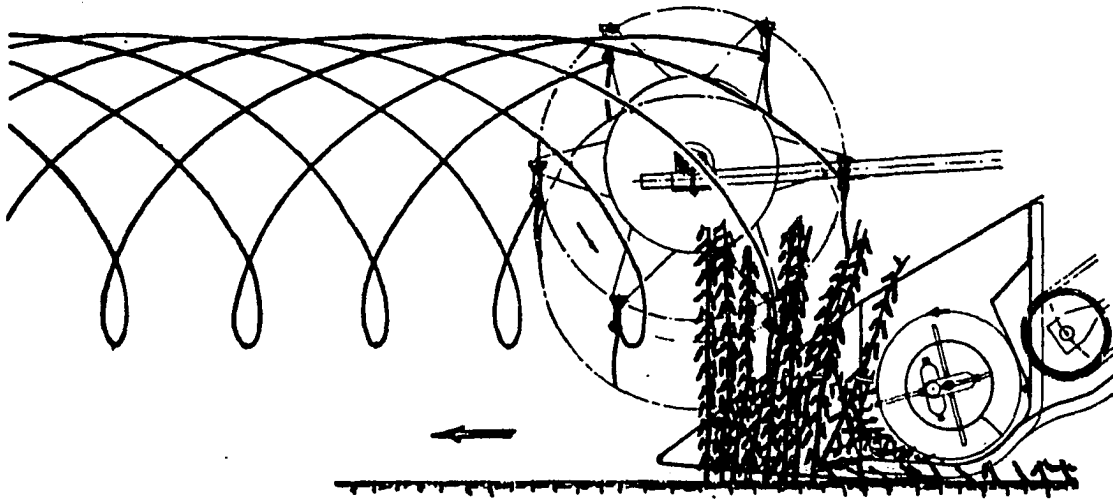


Figure 44. Six bar standard pickup reel operation with a reel index setting of 1.25.

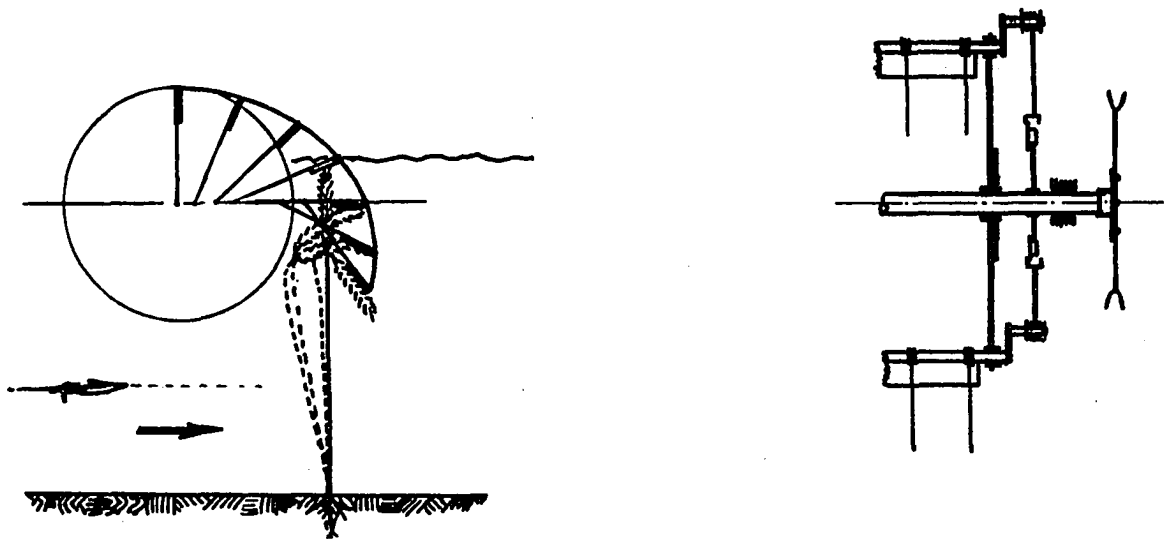
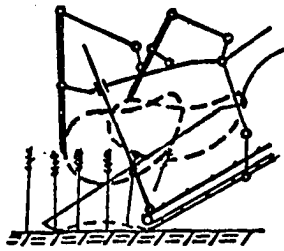


Figure 45. Left, bat reel: influence of bat on a tall plant. Right, "feathering" linkage and mechanism of pickup reel.

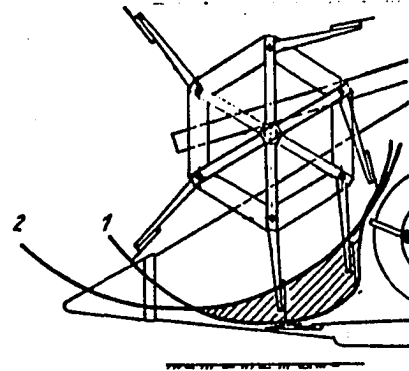
"feathering" action by means of eccentrically mounting "spiders" on the reel drive shaft to achieve a series of parallel four-bar linkage mechanisms, Figure 45, right.

Figure 46 illustrates several interesting mechanical reel variants. Some European combines and plot harvesters make use of a raking reel, Figure 46A. This employs a pair of kinematic quadric chain assemblies, which enable a wide diversity of raking actions (61). Heyde cited the use of a variable radius reel in Russia, Figure 46B. Note the reduction in area of the "dead zone" behind the cutterbar with this device (27). Alexandrovich referred to a "chain-pipe" reel which utilized a pair of roller chains carrying the tined reel bars over large diameter sprockets (1). Feathering action of the reel bars was accomplished by running the cam rollers in an appropriately curved cam rail, Figure 46C. He reported that in a comparison against the pickup reel in beans (species not stated) a reduction in losses of 3% when traveling against the lodged crop, but a 55% reduction in losses when traveling down the lodged crop, was obtained. Lamp et al. referred to preliminary tests with a triangular chain reel (38), while Gustafson's reel, Figure 46D, had a quadrilateral configuration for the chain and cam rail (24). No comparative header loss data was reported for these two reels, but an improved gathering action was claimed.

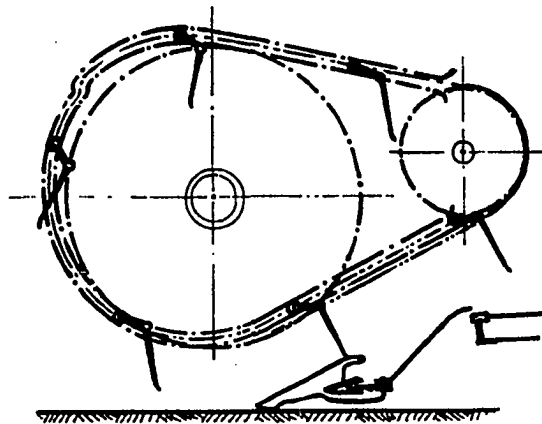
The idea of employing wind, instead of a mechanical contact with the crop, has appealed to a number of inventors, as judged by the patent art. Quick tested a cross-flow fan ("vortex reel"), on a plot combine in soybeans, Figure 47, but concluded that even with air velocities over



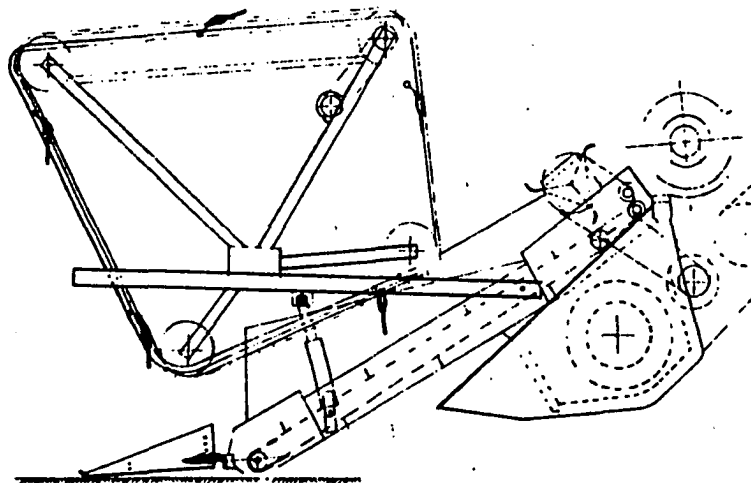
A. Raking reel



B. Variable radius



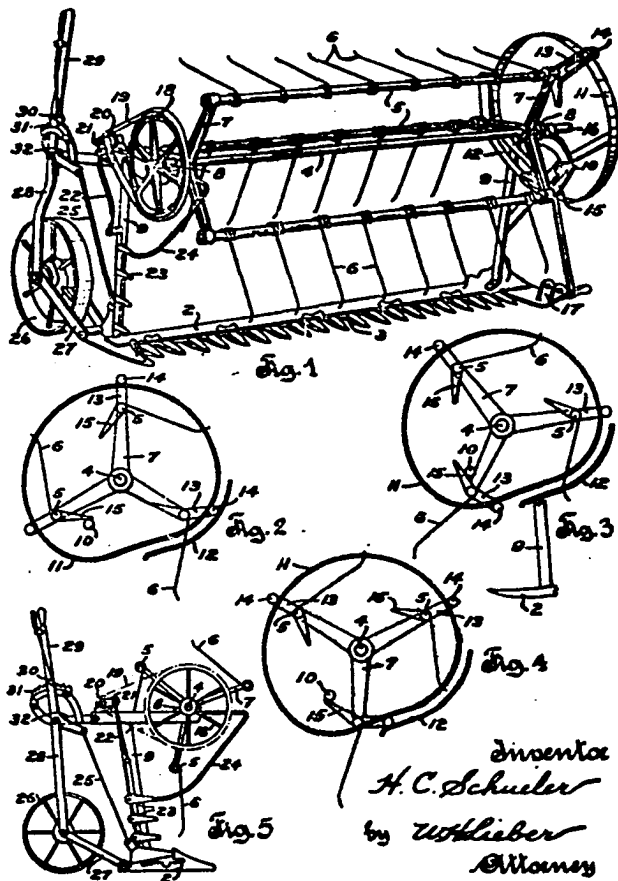
C. Chain bar



D. Quadrilateral track

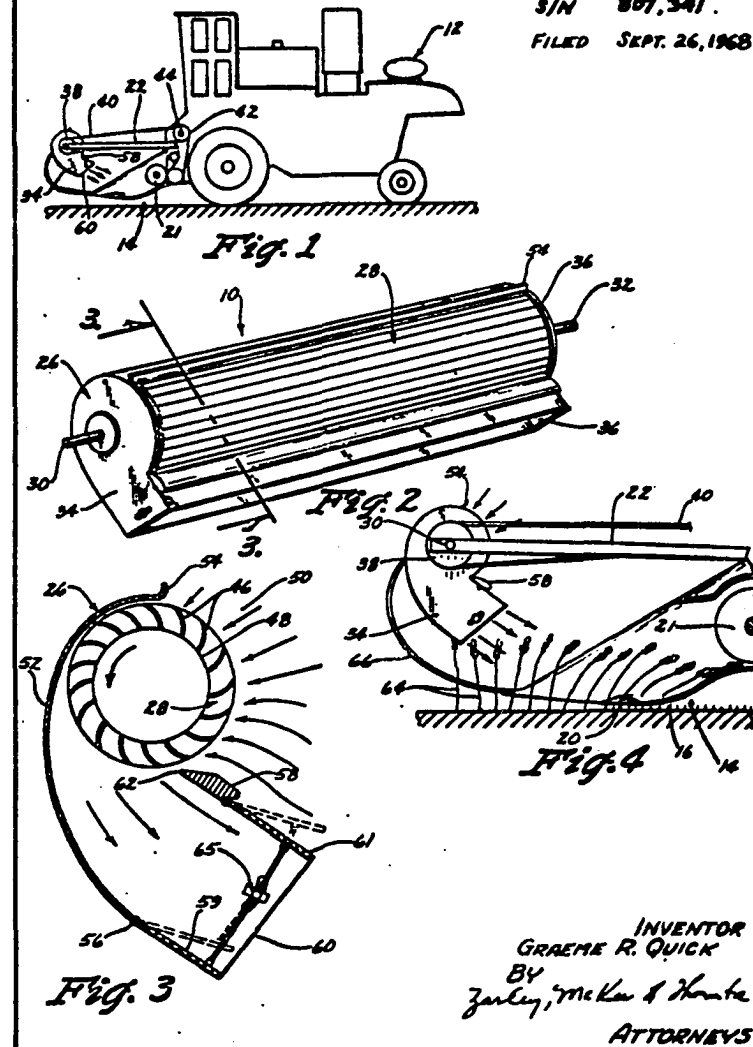
Figure 46. Unconventional combine reel designs.

1,794,646



Disponent
 H. C. Schuler
 by W. H. Lieber
 Attorney

S/N 807,341.
FILED SEPT. 26, 1968



INVENTOR
GRAEME R. QUICK
BY
Zarley, McKee & Hunter
ATTORNEYS

Figure 47. Left, original pickup reel patent. Right, "vortex reel" patent disclosure.

45 mph, which was sufficient to convey the severed plants up the feeder slide to the cylinder, soybean plants which entangled on the divider and cutterbar were not collected. The fan had to be mounted on the reel arms high enough to clear the crop and this caused it to have little control over plants in the cutting zone (61). The Phillips wind reel, on the other hand, used air outlet nozzles suspended between the rows and low enough to effectively clear the cutterbar (57). Park tested this reel in cereals and soybeans and found that it performed well in feeding plants over the cutterbar. He found significant increases in yield using it in Lespedeza and Fescue (54).

Evidently the cumbersome construction and expense of these alternative reel designs has deterred farmers from their widespread acceptance. In general, the bat reel is the standard reel and the pickup reel first option on new combine sales orders.

7.3 Kinematic Analysis of the Reel

The following quantities are pertinent to reel design and performance:

Crop variables - variety, seasonal date, moisture (percent), plant

density (plants/acre), degree of lodging (percent);

Speeds - rotational speed rpm, machine forward speed fpm,

Reel geometry - height above knife, distance ahead of knife, in.,

- reel diameter, in.,

- height of reel center above crop, in.,

Crop height - cutting height, in., plant spacing, plants/ft of row length;

Number of reel bars, number of tines, depth of tines into crop, in., tine shape; tine pitch angle, degrees.

The component of the reel which does the most work on an erect crop is the inside lower edge of the reel bar, so this is the point considered when reel locus and its motion relative to the crop are being considered.

With reference to Figure 48,

let V = forward speed of combine, fpm

X, Y = horizontal and vertical coordinates, respectively, ft

x, y = horizontal and vertical displacements, respectively, ft

u = reel tip speed, fpm referring to reel bar radius

u_x, u_y = horizontal and vertical components of reel bar velocity, fpm

\emptyset, \emptyset_1 = respectively, angular displacement of reel bar radius vector, and angle of point on bar at instant of crop entry, relative to horizontal datum through center of rotation of reel, degrees

t = time, seconds

ω = angular velocity of reel, radian/sec

N = reel rpm

R = reel kinematic radius, ft

L = crop mean height, ft

H = height of reel kinematic center above cutterbar, ft

h = cutting height, ft

The position of any point on the absolute path of the tip of the reel is given by

$$x = V \cdot t + R \cos \emptyset \quad (7-1a)$$

$$y = H + h - R \sin \emptyset \quad (7-1b)$$

where the origin was chosen at a point vertically below the reel axis and

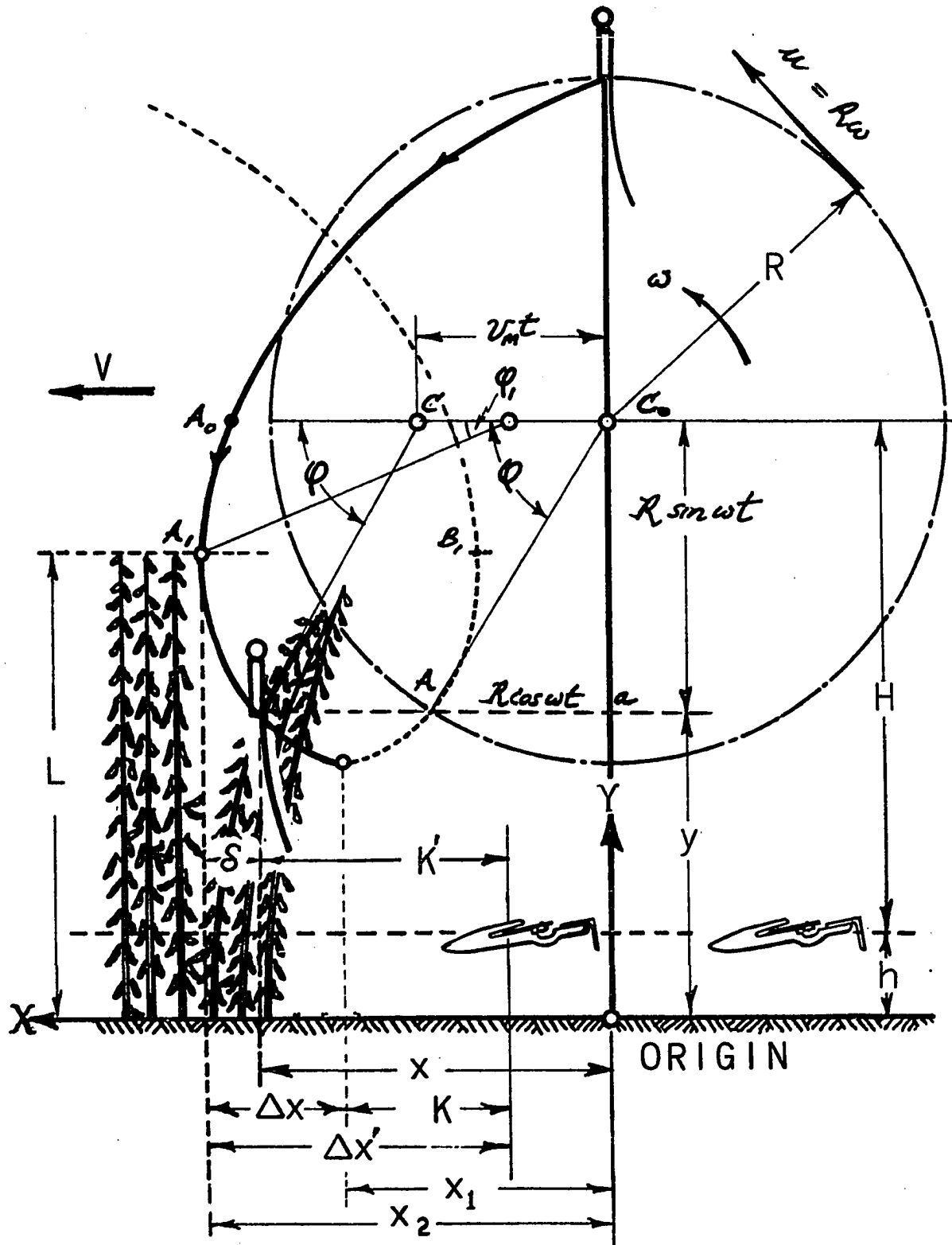


Figure 48. Pickup reel configuration.

its intersection with the ground at time zero. The absolute motion of the reel bar, or tine tip, is cycloidal. A computer program was written to enable the computation of this motion with incremental increases in reel index, λ , where λ = ratio of reel bar peripheral speed to combine speed, i.e.

$$\lambda = \frac{R\omega}{V} = \frac{R\phi}{V_t} \quad (7-2)$$

The program was written to utilize a simplotter sub-routine on the IBM System 360/65 Computer to plot out the result shown in Figure 49. Three plots are reproduced, with superposition of the six reel bars, in Figure 50. A convenient reckoning-chart for selecting reel settings on field machines was prepared and is shown in Figure 52.

An analysis of the motion of the advancing reel bar, shown in Figures 50 and 51, reveals five possible phases of crop and reel interaction:

- I positive thrusting of the crop into the cutting zone,
- II no stalks to cut,
- III no influence of reel bars,
- IV overlapping influence at the higher reel index values, indicative of flailing of the crop - overspeeding might be expected to increase shatter loss of seed heads or pods; and conversely, at low reel index settings,
- V a detrimental thrusting of plants ahead of the cutterbar which might be expected to increase stubble length, cutting, and lodged loss.

The effect of reel index on crop behavior and stubble length was readily observed by employing plastic sticks as ideal plant models in the

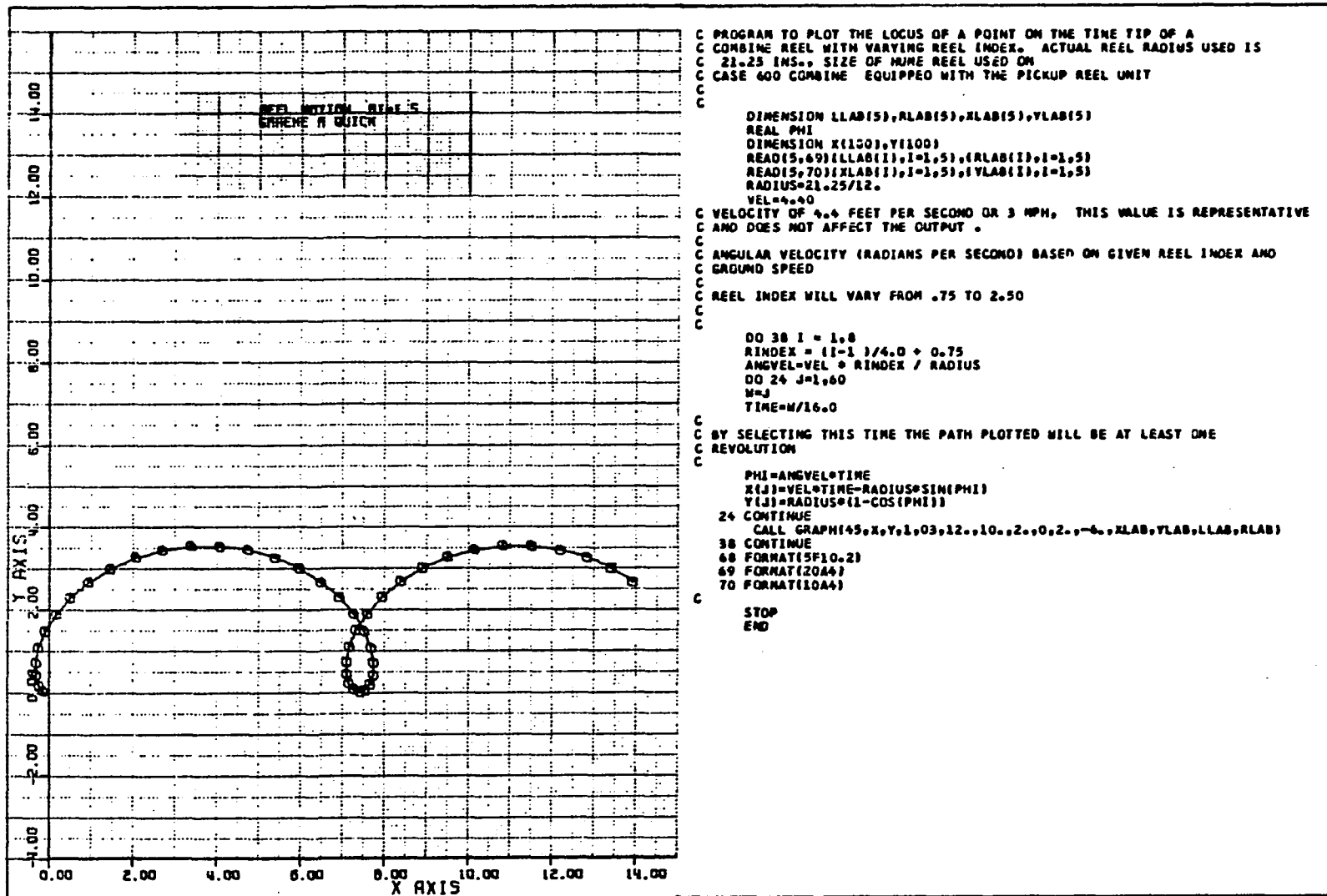


Figure 49. Program to generate and plot the locus of a reel bar.

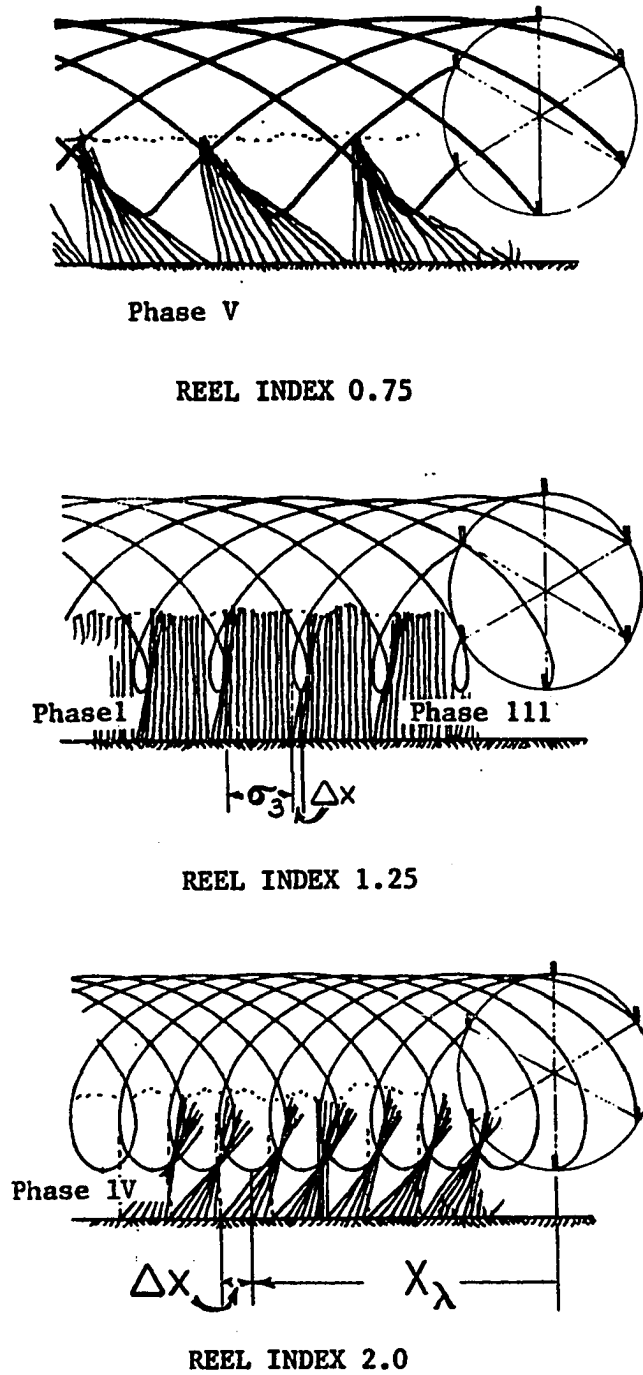


Figure 50. Phases of action of reel bars.

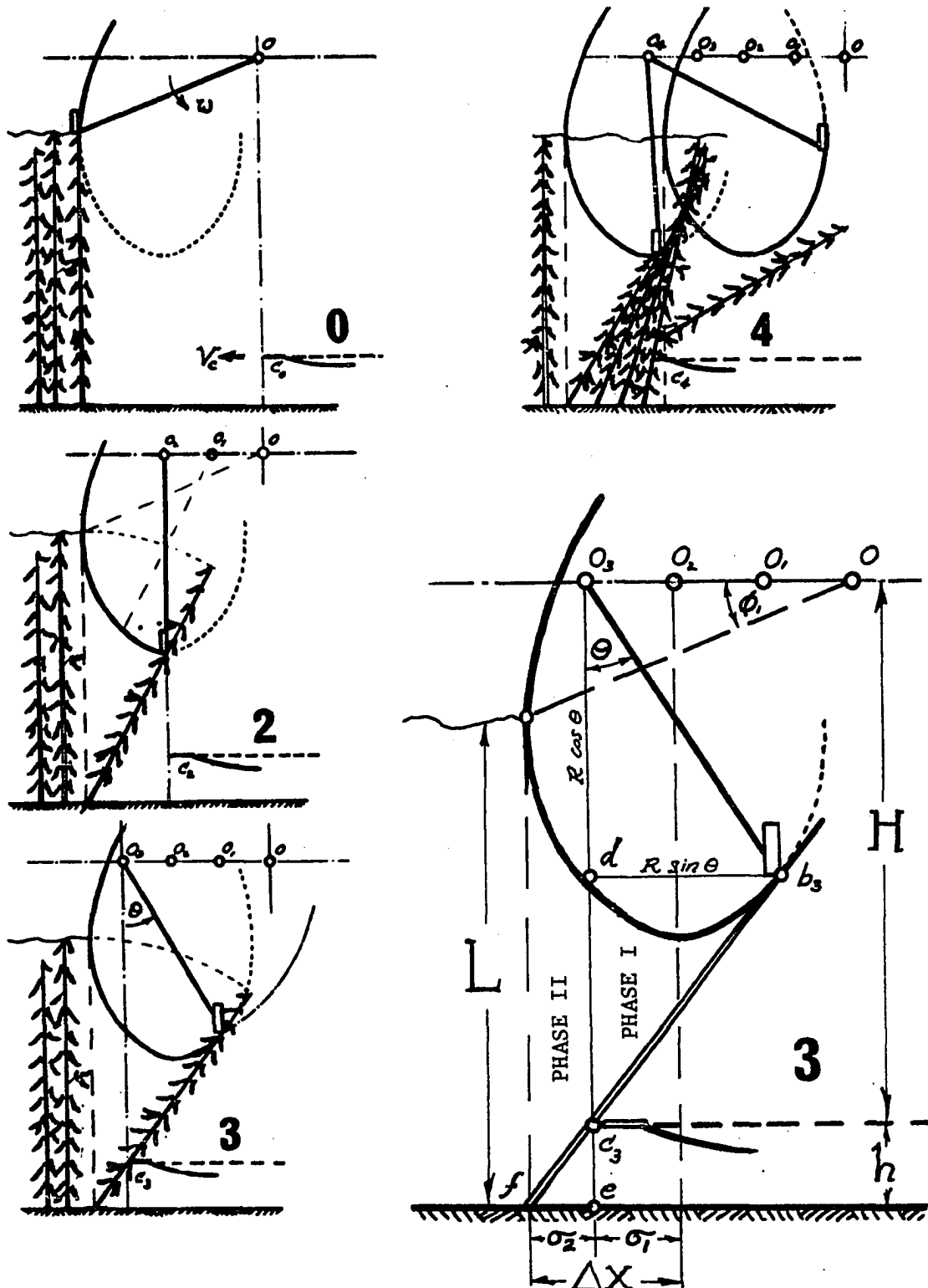


Figure 51. Illustrating reelbar/plant interaction and phases of action of the reel. Zero horizontal reel bar velocity at entry.

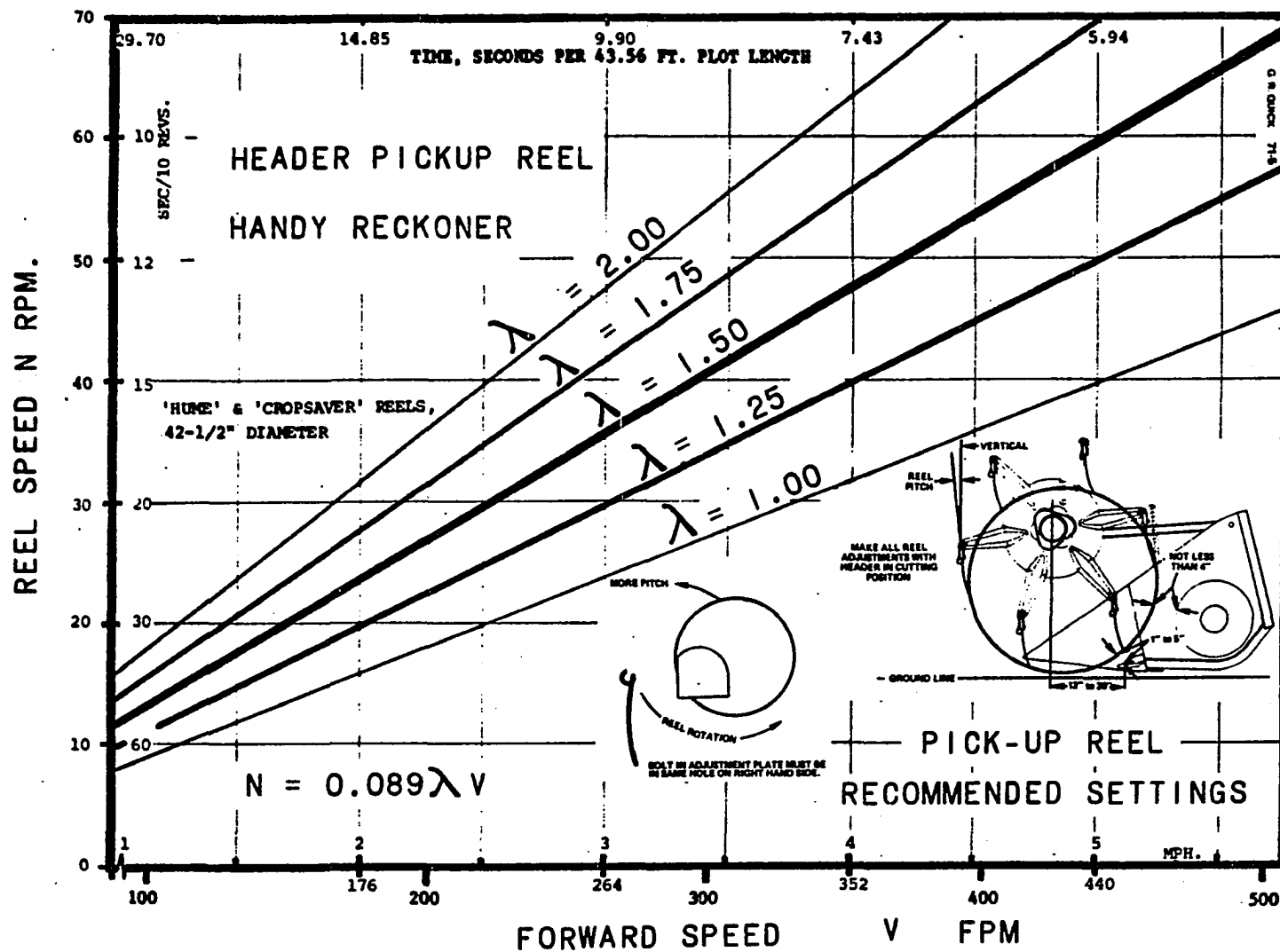


Figure 52. Handy reckoner for field reel settings and speeds.

header lab test facility, Figure 53, right, and Figure 54.

7.3.1 Reel analysis based upon the criterion of minimum disturbance upon entry of reel bar into the crop:

As a starting point for the analysis of reel action, the assumption was made that minimum shatter would occur if the reel bar entered the crop with least shock, as for example, by entry with negligible horizontal velocity

$$\text{Set } u_x = \frac{dx}{dt} = 0 \quad (7-3)$$

$$\frac{dx}{dt} = V - R\omega \sin \omega t \quad (7-4)$$

$$\text{Now } \frac{dx}{dt} = 0 \quad \text{when } \sin \omega t = \sin \phi_1 = \frac{V}{R\omega} = \frac{1}{\lambda}$$

$$\text{i.e. when } \phi_1 = \arcsin \frac{1}{\lambda} \quad (7-5)$$

At the instant of entry of a reel bar into the crop

$$y = L = h + H - R \sin \phi_1$$

$$\text{i.e. } L = h + H - \frac{R}{\lambda} \quad (7-6a)$$

Alternatively,

$$\lambda = \frac{R}{h + H - L} \quad (7-6b)$$

For an erect cereal crop, a reasonable field adjustment is to set the cutting height at say one-third plant height and reel height

$$H = R + \frac{4}{9} L,$$

then

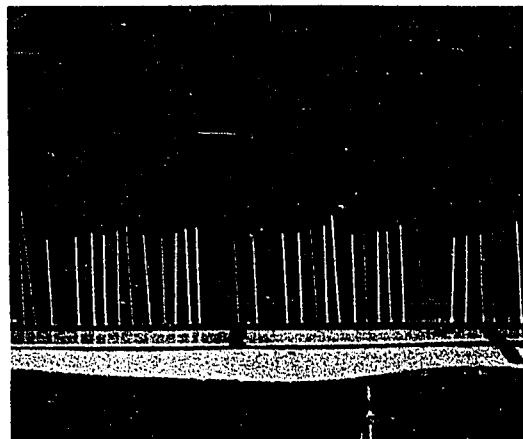
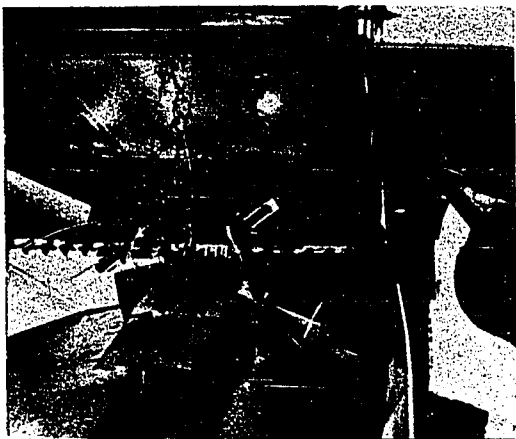
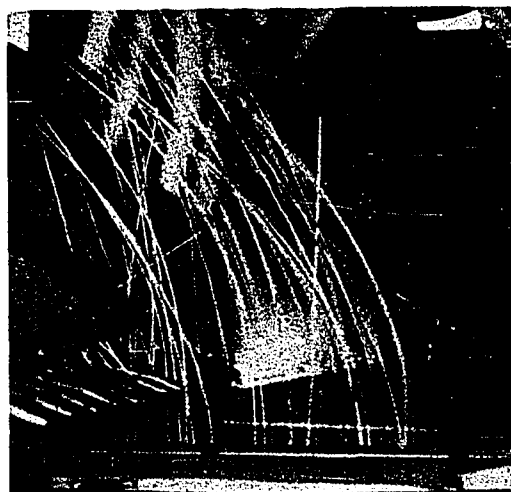


Figure 53. Left, assessment of contribution to losses of header components with auger and reel removed. Crop was forced into header by fan and two air nozzles. Right, measurement of stubble profile length was facilitated by the use of closely-spaced plastic sticks.



Reel index 0.75



Reel index 3.0

Figure 54. Action shots showing effects of reel index on plastic sticks being fed into the lab header.

$$\lambda = \frac{R}{R - \frac{2}{9} L}, \text{ a function of crop height.} \quad (7-7)$$

With a standard 42-1/2 in. diameter pickup reel and using Equation 7-7, $\lambda = 1.12$ in a 10 in. high crop, and $\lambda = 1.46$ in a 30 in. high crop. For the harvesting of soybeans (a low cutting situation) the ideal height of the reel bar above the knife is

$$H - R = R \left(\frac{1}{\lambda} - 1 \right) + L - h \quad (7-8)$$

and for a 42-1/2 in. diameter reel with 9 in. tines, and cutting at 4 in. height, the reel bar and tine positions were calculated for different plant heights and two reel indices:

Table 23. Ideal reel bar and tine setting above cutterbar to provide zero horizontal entry velocity in the harvesting of a crop at a 4 in. cutting height.

	Crop height					
	20 in.		30 in.		40 in.	
Reel index	bar	tine ^a	bar	tine	bar	tine
$\lambda = 1.25$	11.90 in.	2.8 in.	21.8 in.	12.8 in.	31.8 in.	22.8 in.
$\lambda = 1.50$	8.95 in.	0	19.95 in.	10.95 in.	29.95 in.	20.95 in.

^aTine extends 9 in. below reel bar.

7.3.2 Reel contact index:

In order to specify a single quantitative parameter which takes into account reel positional settings as well as reel index, the term "reel contact index," η has been coined, and its derivation is treated below,

after Turbin et al. (78).

Since $\sin \phi_1 = 1/\lambda$ (Equation 7-5)

$$\begin{aligned}\cos \phi_1 &= \sqrt{1 - \sin^2 \phi_1} = \sqrt{1 - \frac{1}{\lambda^2}} \\ &= \frac{1}{\lambda} \sqrt{\lambda^2 - 1}\end{aligned}\quad (7-9)$$

Assume, at first, that the reel axis is set vertically above the cutter-bar. The individual reel bar will impress the crop stems over a distance Δx , Figure 48. If the combine travels distance X_λ during one revolution of the reel, the wave length of the motion, and if there are n bars on the reel:

$$\text{Reel contact index } \eta = \frac{n\Delta x}{X_\lambda} = \frac{n\Delta x}{V \cdot 2\pi/\omega} = \frac{n\Delta x}{2\pi R} \lambda \quad (7-10)$$

$$\text{Now } \lambda = \frac{2\pi R}{VT_\lambda} = \frac{2\pi R}{X_\lambda} \quad (7-11)$$

$$\Delta x = x_1 - x_2$$

$$\Delta x = (Vt_1 + R \cos \phi_1) - Vt_2$$

$$= V(t_1 - t_2) + R \cos \phi_1$$

$$= \frac{V}{\omega}(\phi_1 - \frac{\pi}{2}) + R \cos \phi_1$$

$$= \frac{V}{\omega}(\phi_1 - \frac{\pi}{2}) + \frac{R}{\lambda} \sqrt{\lambda^2 - 1}$$

$$= \frac{R}{\lambda} \left\{ \phi_1 - \frac{\pi}{2} + \sqrt{\lambda^2 - 1} \right\}$$

$$\text{Thus } \eta = \frac{n}{2\pi} \left\{ \phi_1 - \frac{\pi}{2} + \sqrt{\lambda^2 - 1} \right\} = \frac{n}{2\pi} \{f(\lambda)\} \quad (7-12)$$

Example: Consider the typical six bar reel at a reel index of 1.50; i.e. $\sin \phi = 0.666$; $\phi_1 = 41.75^\circ \times \pi/180$, substituting in Equation 7-12:

$$\eta = \frac{6}{2\pi} \{0.232\pi - 0.5\pi + 1.12\}$$

= 0.265 i.e. 26.5% of the stems are fed to the cutter-bar by the reel.

Reel contact index can be enhanced by increasing λ , or the number of reel bars n , or by shifting the reel further ahead of the cutterbar (up to a certain limit). If the reel axis is shifted forward by distance Δx , for example, then contact index is doubled.

The computed values (Table A-13) of the various reel parameters are plotted against reel index in Figure 55. The magnitude of phases I, II and III of the reel bar interaction was determined, see Table A-14. Note that only phase I, the positive feeding part of the cycle, is increased as the reel is moved ahead of the cutterbar.

7.4 Effect of Reel Parameters on Header Loss in Soybeans

Is the zero horizontal velocity at entry for the reel bar a suitable criterion in field practice?

7.4.1 Effect of reel index on header loss - bat reel lab study:

The six bar 42-1/2 in. diameter bat reel was lab tested at various reel speeds at a rate of advance of 2.5 mph. The prediction equation for total header loss π_1 vs. reel index λ was found to be

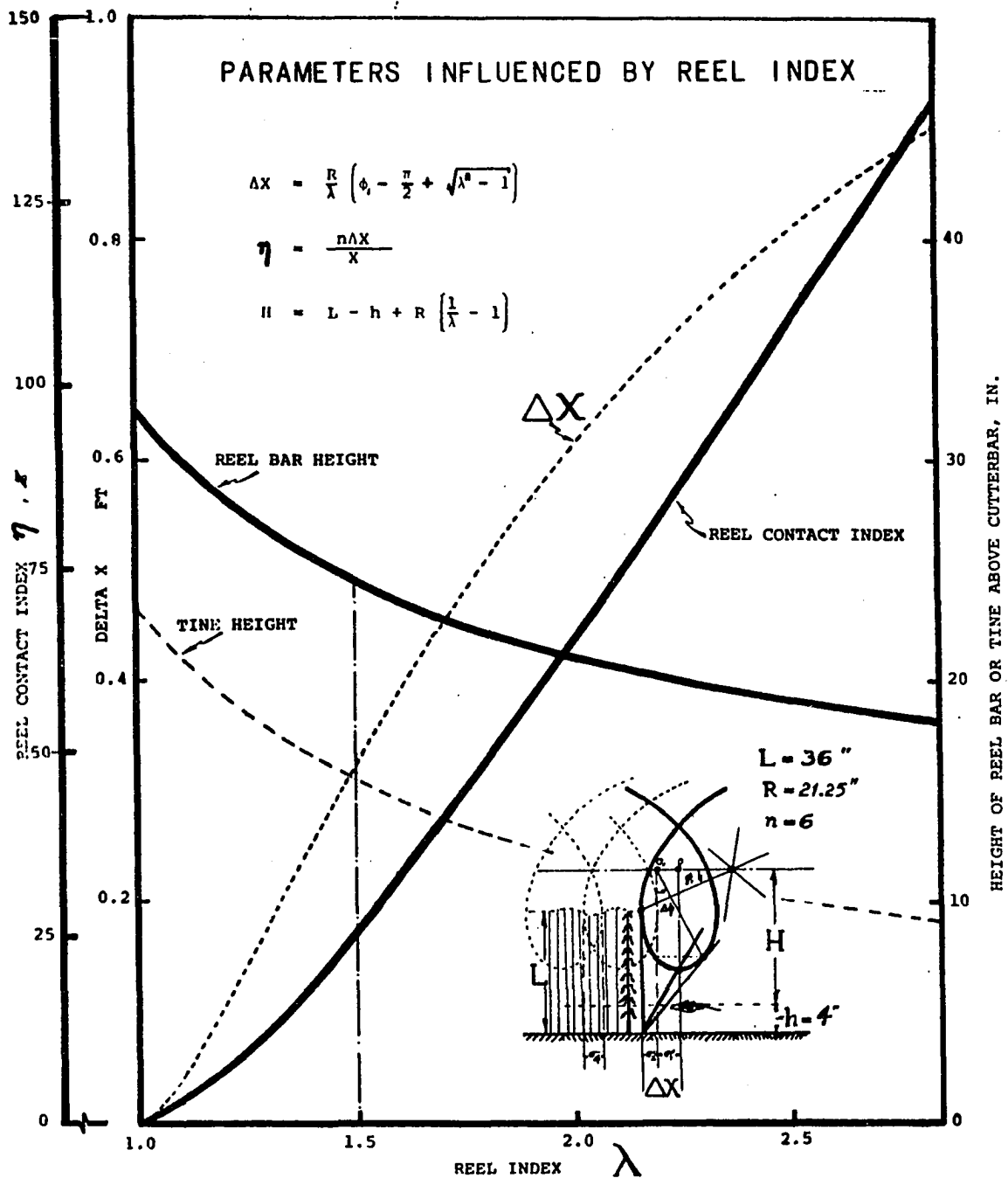


Figure 55. Parameters influenced by reel index. Computations based upon the zero horizontal velocity at crop entry criterion, with reel axis set vertically above tip of cutterbar.

$$\hat{\pi}_1 = \frac{7.7459}{\lambda^2} + 0.8156 \lambda \quad (7-13)$$

$$s_{\pi_1/\lambda} = 1.4849\%$$

Lowest header loss in this test, on Amsoys at 10% MC, was found at a reel index setting of 1.74, Figure 65.

7.4.2 Effect of reel index on header loss - pickup reel:

In a lab test sequence, the rate of advance was held constant at 2.5 mph and only reel speed and moisture were varied. The reel speed x MC interaction was not found to be significant (at the 10% level) over the range 9 to 15% MC in the lab. The regression equation for total header loss π_1 vs. reel index λ at 11.9% MC, had the form

$$\hat{\pi}_1 = \frac{13.3761}{\lambda^2} + 1.3115 \lambda^2, \quad (7-14)$$

$$s_{\pi_1/\lambda} = 1.2402\%; R^2 = 0.9374.$$

The header loss relationships were plotted in Figure 56, and the optimum pickup reel index setting was found to be $\lambda = 1.78$.

Note the deleterious effect of an underspeeded reel.

The traditionally accepted reel index of 1.25 appears to be too conservative in soybeans. A higher value, at least 1.50, is desirable. Higher losses will result if the reel is underspeeded than if overspeeded in erect soybeans, and this effect has been confirmed in field trials, Table A-15, as well as in the trials on the bat reel in the lab. When the

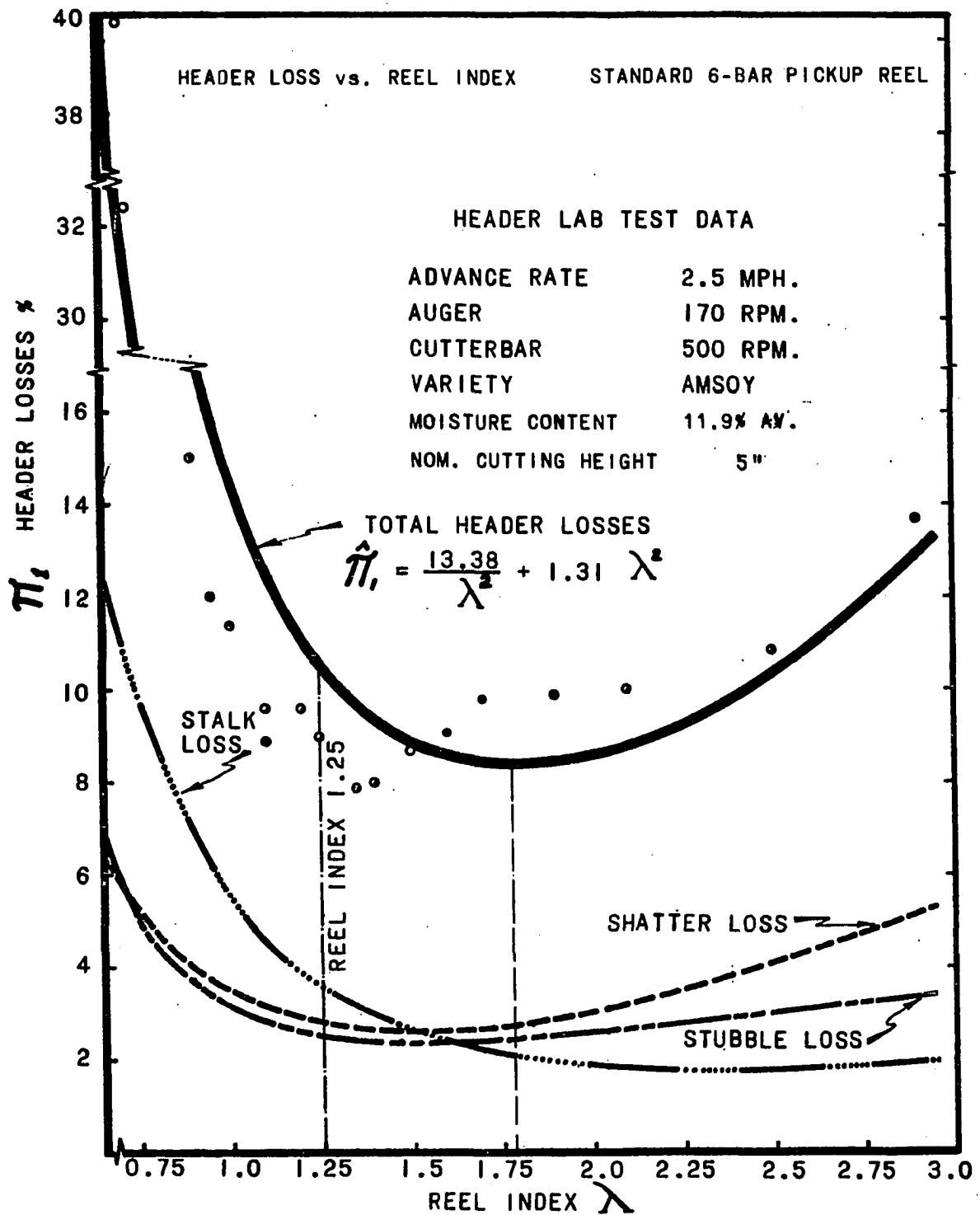


Figure 56. Influence of reel index on header losses, lab test.

crop is lodged, however, the reel positional requirements are different, and it was found that losses increased gradually with reel speed in the range $0.94 < \lambda < 3.12$, Figure 62 (data in Table A-16).

7.4.3 Effect of fore/aft reel position setting on header loss:

The results of this lab test are plotted in Figure 57. The prediction equation for total header loss π_1 vs. reel distance ahead of the cutterbar K (in.) at reel index 1.5 was:

$$\begin{aligned}\hat{\pi}_1 &= 5.0324 - 0.1072K + 0.0060 K^2 & (7-15) \\ s_{\pi_1/K} &= 0.6436\%, \quad K_{\text{optimum}} = 8.93 \text{ in.}\end{aligned}$$

This lab test data indicated that the optimum forward setting for a pickup reel in erect Amsoy soybeans was 8.93 in. Field testing confirmed the need to set the pickup reel axis at least this far ahead of the cutterbar. If the crop was lodged, header recovery was improved if the reel was set further ahead, even as far as 20 in.

7.4.4 Effect of reel height setting on header loss:

The lab results with the pickup reel set 12 in. ahead and at reel index 1.5 are illustrated in Figure 58. The prediction equation for total header loss π_1 vs. reel tine height H (in.) at reel index 1.5 was:

$$\begin{aligned}\hat{\pi}_1 &= 7.1154 - 0.8152 H + 0.0462H^2 & (7-16) \\ s_{\pi_1/H} &= 0.5848\% \quad \text{and} \quad H_{\text{optimum}} = 8.82 \text{ in.}\end{aligned}$$

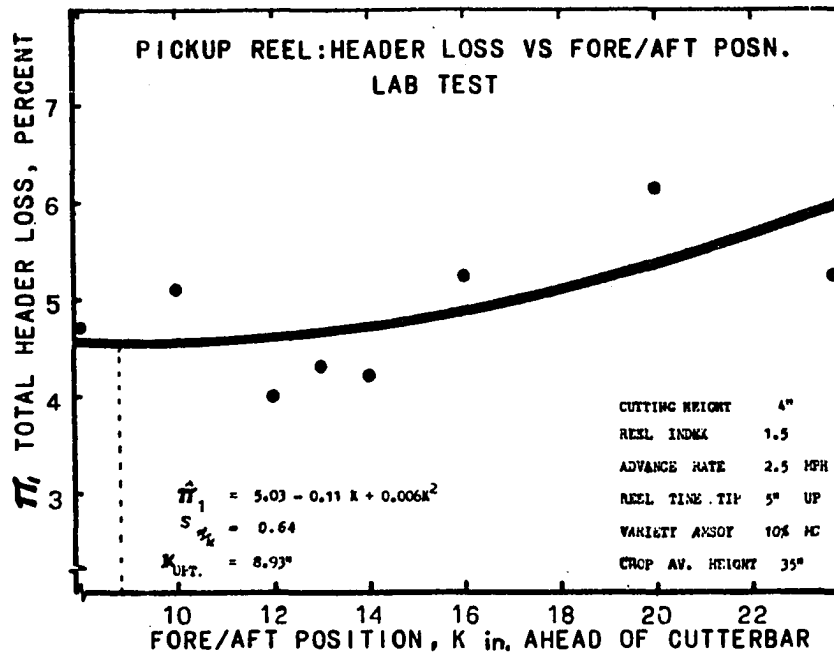


Figure 57. Influence of fore/aft position on lab header loss, pickup reel.

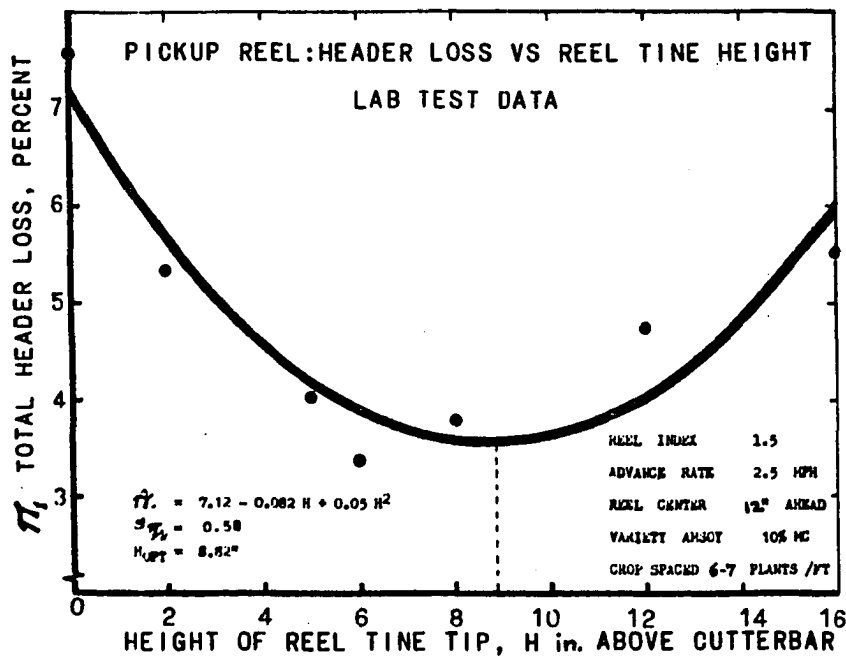


Figure 58. Influence of reel height on lab header loss, pickup reel.

Better performance was obtained in the field with the reel set lower, and if lodging was severe the reel tines could be set as far down as to be level with the cutterbar, for better stalk recovery.

If the reel was raised to the position indicated by theory (from Equation 7-8), for the 35 in. Amsoy crop, the reel tine would be set 15.95 in. above the cutterbar at reel index 1.5. When the reel was raised to 16 in. in the lab, the plants tended to be thrust forward by the cutterbar against the oncoming crop, pile up, and fall out of the header.

7.4.5 Summary - reel settings:

It was concluded that, with the reel and combine operating at reasonable speed settings (below 3 mph with reel index 1.50) the zero velocity at entry criterion was not practicable in the low cutting of the soybeans. Under lodged conditions it is probably inapplicable for any crop.

The need to positively feed soybeans onto the platform, and to provide a barrier to prevent tall crops from being thrust out by the cutterbar and auger, assumed more importance than the requirement for zero horizontal velocity of the reel bar at entry. The ideal speed and positions for the pickup reel in an erect Amsoy crop, as indicated by lab tests and partly confirmed in the field, were within the ranges:

- (1) reel index: 1.5 to 1.9 (1.78)
- (2) reel height: 5 to 10 in. (8.82 in.)
- (3) position ahead: 7 to 14 in. (8.93 in.)

In lodged and tangled conditions crop pickup was improved by

- (1) pitching the reel tines forward
- (2) setting the reel further ahead and the tines nearer the ground.

These conditions departed completely from the zero velocity at entry criterion. With the standard reel tine set level with the cutterbar, and cutting at 4 in., with reel index 1.50, results in the reel entering a 35 in. crop with a horizontal velocity of 1.7 times the forward speed of the combine. There was also the tendency for increased "wrapping" and repeating on the reel, as miscreant plants were carried around the top by the reel bar. This can be a definite operational problem in severely lodged crops. Lodged crops evidently posed different requirements in field operation than erect soybeans.

The influence of forward speed on optimal reel settings was not considered in this work. Changing forward speed introduces two new variables to be considered as well as reel index, namely, cutterbar advance ratio and auger index.

7.5 The Vertical-Drum Reel

The Lynch commercial row-crop header attachment, Figure 60, was originally conceived as a replacement for the reel in harvesting sorghum. A four-30 in. row unit was purchased and installed on the Case 660 10-ft header. After two seasons of tests the results were impressive, as seen in Tables 24 to 26 and Figures 61 and 62. (Data in Tables A-17 and A-18).

The Lynch row-crop vertical-drum reel significantly reduced header loss under all conditions and speeds in the test comparisons with the standard header. Header loss was reduced by as much as 53.5% in lodged conditions, primarily due to the reduction in stalk loss. It was apparent from the operator's perspective that the vertical reel drums were providing more positive control over the plants as they were being cut

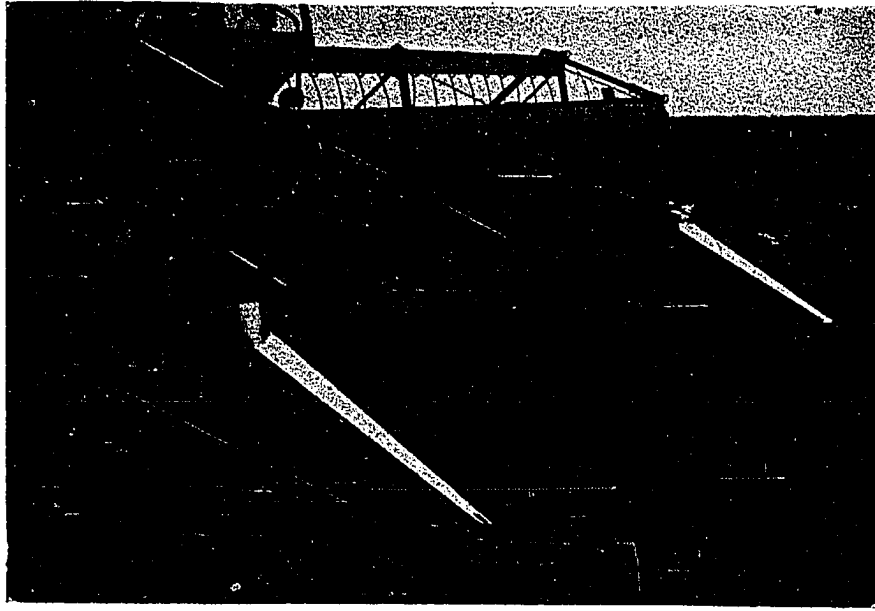


Figure 59. Bethard floating row dividers and Hume oversize pickup reel fitted to John Deere combine.

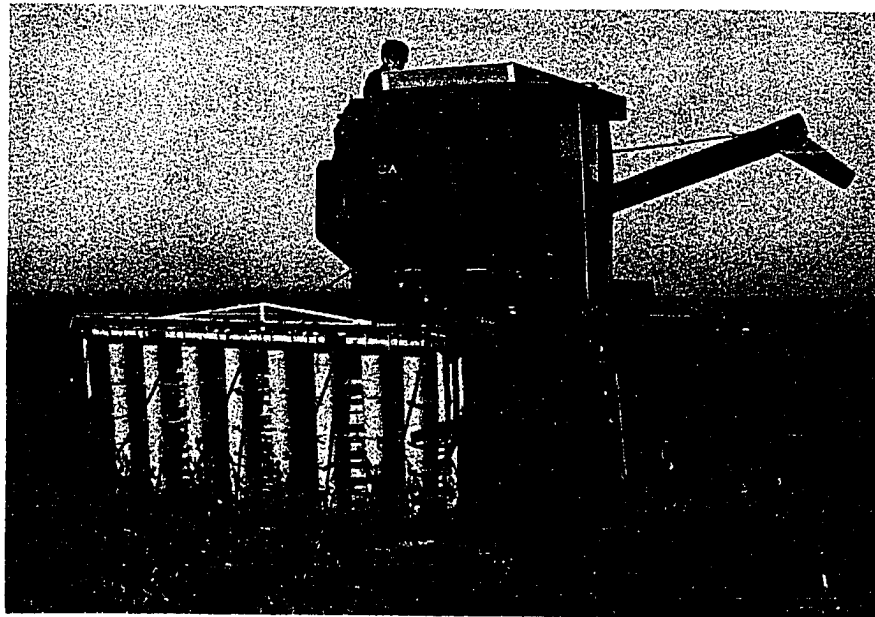


Figure 60. Lynch row-crop attachment.

Table 24. 1970 field comparison^a between Case 660 combine with Lynch vertical-drum reel and standard Case 600 combine, at three reel indices. Both equipped with automatic header height controls. Nominal speed for all tests was 2.5 mph. Variety Amsoy at 19.3% MC, following rain. Results shown in Figure 61.

	Average header losses, percent				Av. stubble length, in.
	Shatter	Stalk	Lodged & stubble	Total ^b	
Standard reel					
14 in. ahead	2.43	6.80	1.81	11.04	6.30
8 in. up					
Lynch drum reels ^c					
6 in. ahead	2.25	3.60	0.89	6.74	5.70
3 in. up					
Conclusions (Headers)	n.s.d.	**	n.s.d.	**	Diff. sig. at 10% level (separate AOV)

^aTwo-way analysis of variance with stubble length as covariate. Treatments: two machines (Lynch and standard), three reel indices, two replications. Two sub-samples per plot. Directions of travel were not significant. Directions, headers, reel indices - interactions were found not significant, so directions were included as replications.

^bThe Lynch attachment reduced header loss by 38.9% in this crop, which was 10% lodged.

^cHighly significant machine x reel index interaction.

Table 25. 1971 field comparison^a between Case 660 combine equipped with Lynch reel and standard Case 600 combine, at two reel indices. Both combines equipped with automatic header height controls. Nominal combine speed for all tests was 1.93 mph. Variety Amsoy 11% MC. Results shown in Figure 62.

Treatment		Average header loss, percent					Av. stubble length, in.
Header	Reel index	Shatter	Stalk	Lodged	Stubble	Total ^b	
Standard header	1.25	4.11	12.02	1.59	1.05	18.76	4.38
	2.0	5.19	13.59	3.12	1.53	23.43	4.24
Lynch vertical-drum reel	1.33	3.01	3.29	2.25	1.53	10.07	5.29
	2.34	2.47	4.22	1.18	1.68	9.56	4.71
Conclusions (headers)		Diff. sig. at 10% level	**	n.s.d.	n.s.d.	**	* (AOV)
Conclusions (reel indices)		n.s.d.	n.s.d.	n.s.d.	n.s.d.	n.s.d.	n.s.d. (AOV)

^aTwo-way analysis of covariance, with stubble length as covariate. Treatments: two headers (standard and Lynch), two reel indices (1.25 and 2.0). Directions of travel were not found significant and were pooled for a total of four replications. Four sub-samples per plot.

^bThe Lynch attachment reduced total header loss overall by 53.5% in this crop, which was 30% lodged (the Lynch attachment had crop lifting row dividers). Header x reel index interaction was found significant (at the 10% level) on lodged and total losses.

Table 26. 1970 field comparison^a between Case 660 with Lynch attachment and standard Case 600 in the three varieties, Amsoy, Hawkeye and Corsoy, av. MC 19.3%. Machine speed: nominal 2.5 mph, reel index 1.25.

	Average header losses, percent				Av. stubble length, in.
	Shatter	Stalk	Stubble	Total ^b	
Standard	1.07	3.11	1.50	5.68	6.15
Lynch	0.72	2.41	1.20	4.33	5.73
Conclusions ^c (tests on headers)	*	Diff. sig. at 10% level		n.s.d.	*
					n.s.d.

^aTwo-way analysis of covariance, with stubble length as covariate; treatments: headers (2), varieties (3). Direction of travel was not found to be significant (at the 10% level) and so the two directions were pooled to provide a total of four replications, with 3 sub-samples per plot. Lodging was negligible in Hawkeye and Corsoy and about 10% in Amsoy.

^bThe Lynch attachment reduced total header loss overall by 23.9% in this comparison, a significant reduction.

^cNo significant interactions at the 10% level between headers, varieties and directions.

than the standard reel. It was necessary, on the other hand, for the operator to pay closer attention to driving the unit so that the row dividers remained on row centers, Figure 64, otherwise stubble length was substantially increased (a problem also found in a preliminary trial on the Hesston Soybean Savers, or "Bean Buckets"). The Lynch row dividers performed very effectively as crop lifters, and this may have been a major contributor to the improved header performance under lodged conditions.

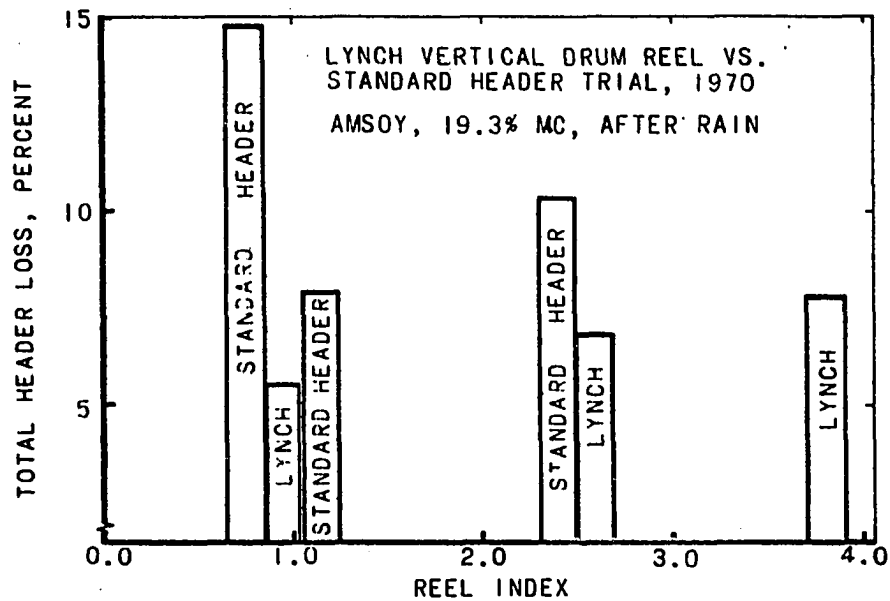


Figure 61. Lynch and standard headers compared at three reel indices in 1970 field test.

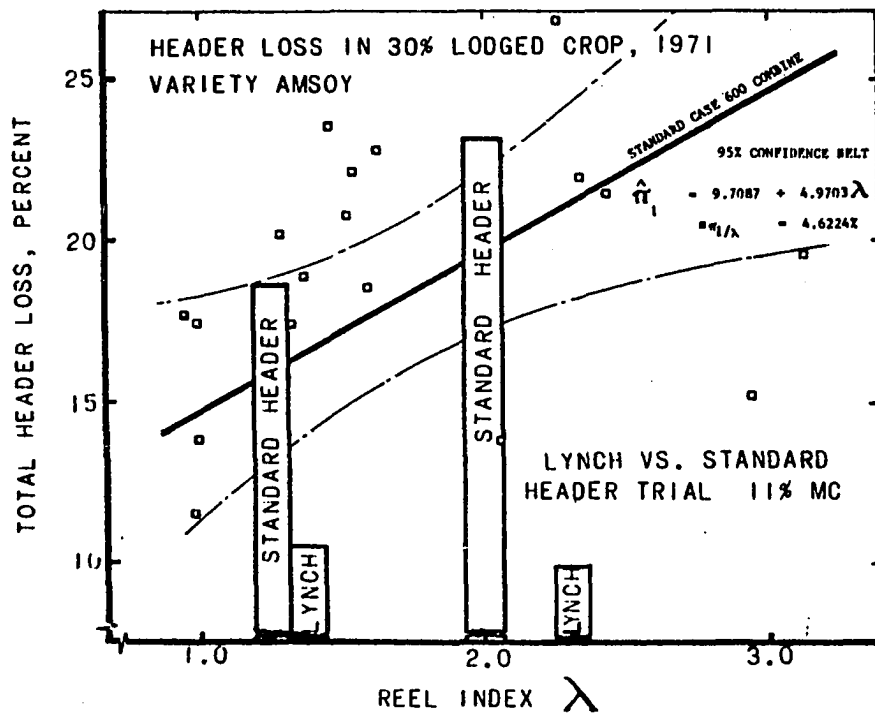


Figure 62. Lynch and standard headers compared and influence of lodging on reel index characteristic, 1971 field tests.

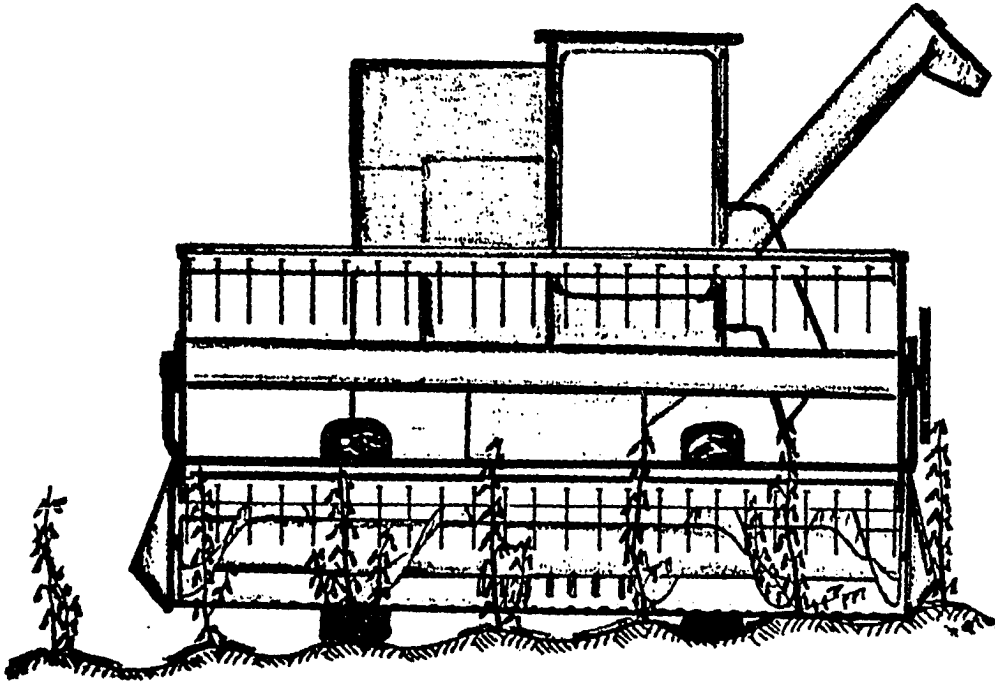


Figure 63. Ground irregularities, incorrect wheel spacing and erratic steering cause tilting of the header and increased stubble length.

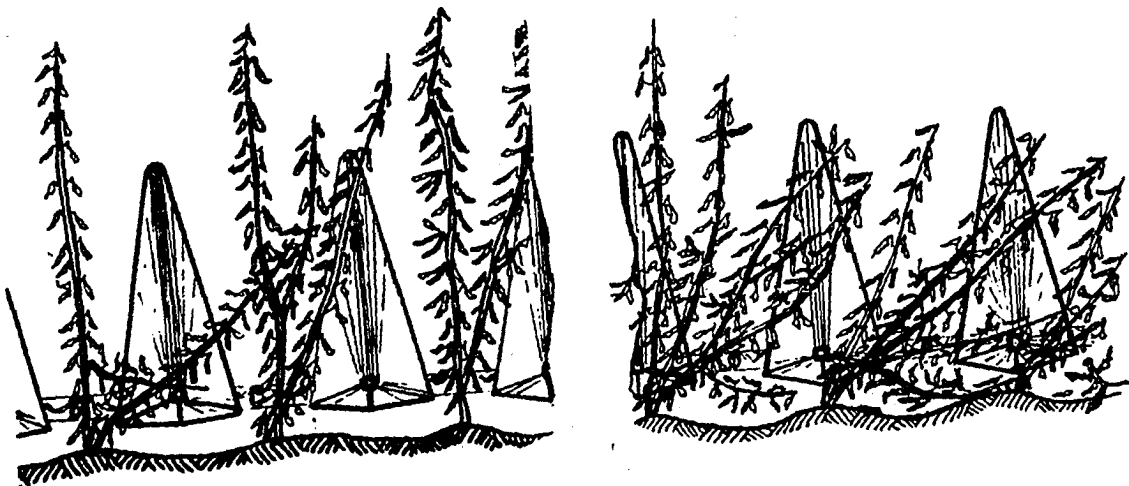


Figure 64. Operation of row-crop attachments off row-center tends to increase stubble length and header losses.

7.6 Operation at High Forward Speeds Without a Reel

So far this analysis has not accounted for the dynamic effects of the cutterbar upon the plants. It has been noted that the cutterbar thrusts the base of the plant stems upward and forward following cutting. It is evident that there should be a combine speed where the platform could move "under" the stems and collect them without the aid of the reel if the cutterbar could cope with the higher speeds. Orechov and Tarasenko (52) discussed this type of operation, and suggested that at speeds above 5 mph the combine could be operated satisfactorily in standing cereals without the benefit of a reel, Figure 66. Just what type of cutterbar was utilized in their combine studies was not stated, but it is obvious that they must have considerably speeded up the knife to attain these forward speeds if it was similar to the 3 in. reciprocating units used in the western world. Higher reciprocating speeds would enable a higher capacity, at the cost of considerably reduced cutterbar operating life.

7.7 Platform and Auger

The demise of the draper-conveyor platform and adoption of the auger was not a step conducive to the reduction of header loss in soybeans. There is no immediate likelihood, however, of a departure from the simplicity and ruggedness of the auger in favor of a return to the draper-conveyor. Draper-conveyors required more head room above the cutterbar and, when the header was operated near ground level, soil and trash would accumulate and frequently lead to back-feeding and jamming of the draper. The problem with the standard auger and platform is the lack of space on the feeding apron to lay down a tall crop in an orderly fashion, Figure 67.

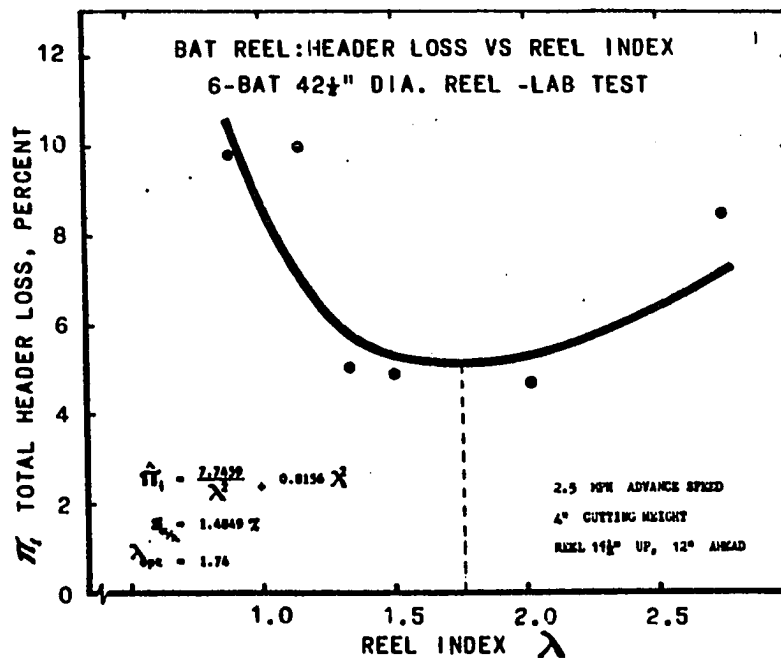


Figure 65. Influence of reel index on header loss, lab study on bat reel.

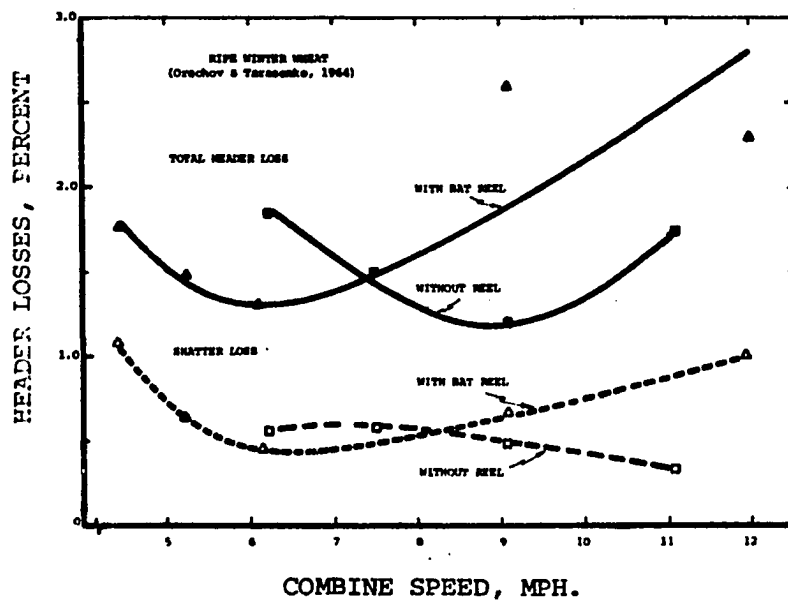
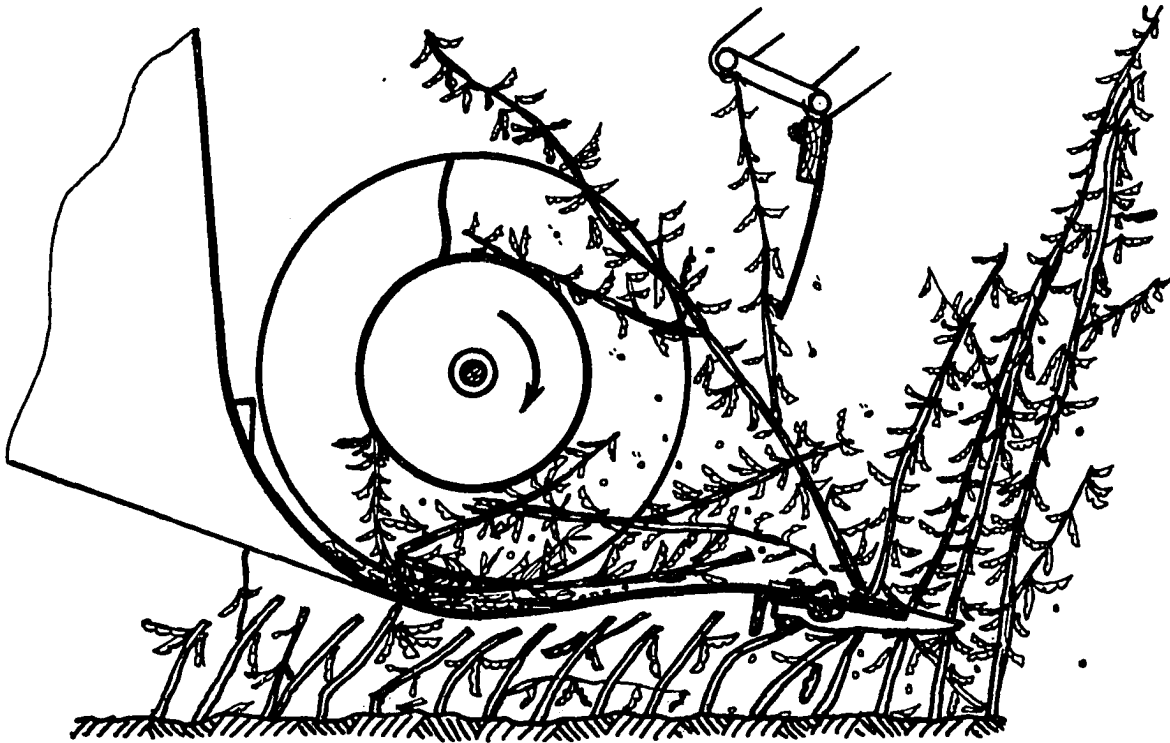


Figure 66. Russian results comparing header losses. Operation in winter wheat, with and without a reel (52).



Typical Auger Characteristics

Auger flight diameter - 20 in., drum diameter - 12-1/2 in., pitch - 18 in.
 Distance from tip of knife to a point vertically below the axis of the
 auger - 17 in. Auger flighting to housing clearance - 3/8 in., adjustable.
 Auger speed range - 130 to 200 rpm, standard 170 rpm for soybeans.
 Auger tip speed at 170 rpm - 10.11 mph.
 Auger index at 170 rpm and 3.0 mph - 3.38
 No-slip conveying speed at 170 rpm = Tip speed x tan (helix angle)

$$= 10.11 \times \frac{18}{20\pi} = 2.90 \text{ mph} \quad (7-17)$$

Center feeding mechanism - four sets of four retractable fingers.

Figure 67. The conventional auger and platform concept was not originally intended for cutting low in tall crops.

Headlie Taylor's original augers used small center tubes and open flighting. On modern machines the auger has been stiffened with a tube diameter of 10 to 14 in. in order to provide the rigidity necessary for headers up to 24 ft width, and to reduce straw-wrapping around the auger in crops such as wet rice.

7.7.1 Effect of extending the platform:

Huitink, who built a paddle conveyor system to replace the auger, but with adverse effects on header loss and capacity, also tested the Case cutterbar extension attachment in 1970 (30). This attachment consisted of a platform extension sheet which simply put the cutterbar 10 in. further ahead of the auger. His 3-factor factorial experimental design included two levels of each of the three treatments - forward speeds (2.5 and 4.0 mph), reel positions (6 in. and 12 in. ahead of cutterbar) and platform floors (standard and 10 in. extended). Unfortunately, his results were only reported in bu/acre units, and plot yields (which were known to vary considerably) were not recorded. This possibly confounded the results. Header loss was lower with the extended platform, but the difference was reportedly not significant. The loss reduction may have been explained by the significant stubble loss reduction he obtained with the extended platform header. A covariate analysis was not performed.

In 1971 this experiment was repeated, and again there was a reduction in header loss due to using the 10 in. rigid platform cutterbar extension, but the difference was not significant at the 10% level, Table A-19.

7.7.2 Header loss variations across width of the machine:

Huitink (30) cited unpublished Annual Reports from Nebraska and Illinois studies indicating higher shatter losses at the middle rows than at the outer rows with standard headers. Down-the-row spot samples were taken on individual middle and outer rows of six-row headers. Both studies led to the conclusion that plants accumulated on and behind the cutterbar due to inefficient conveying. Excessive shatter was said to result from this factor and from damaging blows from auger screw pitches and the retractable feeder fingers.

These results may be interpreted another way. It is submitted that a six-row header is not wide enough for such an investigation. It is quite possible that the outer row dividers could materially aid in reducing loss at the outer row. The movement of crop material at the outer rows would be different from that at the middle two rows. If, indeed, higher losses were due to the feeder fingers and crop build-up on the platform, one would expect that extending the cutterbar ahead would diminish the problem. Nave et al., of the Illinois group which tested an air conveyor extending the cutterbar 24 in. ahead (49), have not reported any data on the effect of the extended platform on the across-header loss distribution.

7.8 Influence of Auger Speed on Header Losses

Nave et al. investigated the effect of reducing the speed of the John Deere 13-ft platform auger from 197 rpm to 145 rpm and found a 25% increase in shatter loss (49). They concluded from this and from movie studies that build-up of plant material due to inadequate crop removal and consequent

impedance of the movement of incoming plants was responsible for the increased losses.

The header lab was used to test the effect of auger speed on header losses in a single-row harvesting situation. Header losses remained substantially constant over the range of auger speeds 90 to 240 rpm and at 2.5 mph, Table A-20. Slope and quadratic terms were not significant in the regression analysis of header loss on auger speed.

The increasing header loss at lower auger speed in the field (49) would indicate a materials-handling problem. When plants are not removed fast enough by the cross conveyor, incoming plants are subjected to more action by the reel and cutterbar. If combine speeds should increase substantially in the future, then the conveying capacity of the auger could become critical. Romer and Urban studied the manner of crop conveying on the platform (65). They stated that plant stems were conveyed by the auger in the space between the outer edge of the flighting and the trough (and not between the flights as in grain conveying). If this is the case then it is probable that axial slippage could be reduced by manufacturing a conveyor with a fluted periphery, for more aggressive feeding and higher capacity at the same auger speed.

8. CUTTERBARS

The reciprocating cutterbar has been identified a posteriori, as the component of the standard header contributing most to header loss.

Cutterbar-related losses may occur directly by:

1. cutting too high
2. failure to cut stalks and slippage under the cutterbar
3. uprooting of plants and plugging;

or indirectly, when plant parts are not collected as follows:

1. pod cutting with shatter
2. stalk double cutting
3. branch snipping
4. pod shatter and stalk impacts
5. pod stripping and dropping
6. shatter due to separation of plant from plant.

An ideal cutterbar design would have these capabilities:

1. uniform cutting at or near ground level and occasionally in the soil (it is assumed that the operator does not want to cut constantly below ground or have dirt continually passing through the combine)
2. cut with least stem disturbance or slippage, and without stripping pods
3. thrust the plants onto the platform in a predetermined fashion
4. cut cleanly for low cutting energy
5. high capacity or throughput
6. durability and maintenance of cutting edge

7. balanced, with modest shock loading on drives, but with built-in overload protection
8. flexibility to accommodate to ground irregularities.

Consider the modus operandi of the standard cutterbar, a 135 year old concept which was adapted into the combine from the mower and binder. The combine cutterbar has a thinner gage knife section (usually 0.10 in. thick) and lighter knife back, presumably because it operates under a somewhat less harsh environment than the mower. More importantly though, the unit needs to be lighter and has to be operated slower (a typical 450 rpm vs. 800 rpm) because combines are wider than mowers. This lower speed ensures an acceptable service life for the unit and drives, which are subject to the unbalanced cyclic loading produced by the reciprocating knifebar.

8.1 Fundamentals of Cutting

Stem cutting is essentially a separating action: one part of the plant being severed from another by at least two counteracting transverse shear forces. Stresses in bending, torsion and tension, and some plant deformation, may also occur during cutting. The separating action may be produced in several ways:

1. Two-element shear, as with the conventional cutterbar - by one moving element traveling over a stationary counter-edge on one or both sides of the knife blade.
2. Two-element shear - by two edges sliding past each other in opposite directions, e.g. the double knife cutterbar.
3. Single element (impact) cutting - by a single moving blade. The plant material itself provides enough resistance to engender the

opposing force, e.g. the impact cutting action of flail choppers and rotary mowers of the disc or helical type (5, 64).

4. Multiple single element - by the smaller individual teeth on band- or circular-saw blades (5, 43).

Koniger described the stem cutting action as that of a wedge driven between the cell network (35). He suggested that stem cutting essentially proceeded as follows:

The force components at right angles to the wedge surfaces cause separation of cells and plant parts. The edge picks out a line of least resistance and a shear plane failure proceeds ahead of the blade. If some sliding on the blade can occur, the edge will have a more effective sawing action due to microscopic notching on the blade. This sawing action is, of course, accentuated when serrated blade edges are used.

Thus Koniger disagreed with Stroppel's idea (74) that fibrous material was severed by concentrated forces along the knife edge. Reineke (63), in considering orthogonal cutting of wood (cutting perpendicular to the fiber axis) suggested, in essence, the following cutting theory:

Ideally, to initiate penetration, the cutting tool should have an edge fine enough to enter the spaces between the wood molecules. To accomplish this would require a tool with molecules smaller than the intermolecular space. Since this is an impracticality, the cutting edge must press upon the fibers as integral structural units and cause local deformations until molecular cohesion is overcome and the fibers break.

Reineke further suggested that a possible sequence of action in fiber

severance was:

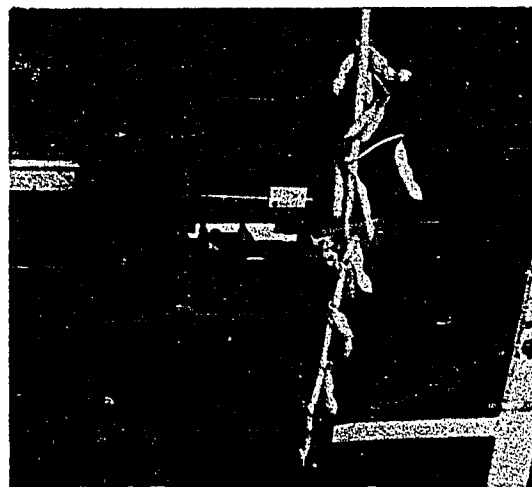
- (1) cell bending
- (2) top wall of cell (nearest blade) contacts bottom wall on the opposite side of the cell cavity. Additional resistance is supplied by the side walls, and the top wall of the next cell layer
- (3) the effect on the cell bundles is similar to that of a beam on an elastic foundation
- (4) the length of the bent fibers must increase and leads eventually to failure in tension, at the most highly stressed point within the zone affected by the cutting edge (precise location of this failure is indeterminate - due to anisotropy of the material)
- (5) the volume of the fibers deformed by a sharp blade (small wedge angle) is smaller than for a dull blade, so less energy is required in cutting with a sharp blade.

8.1.1 Effect of blade speed on cutting:

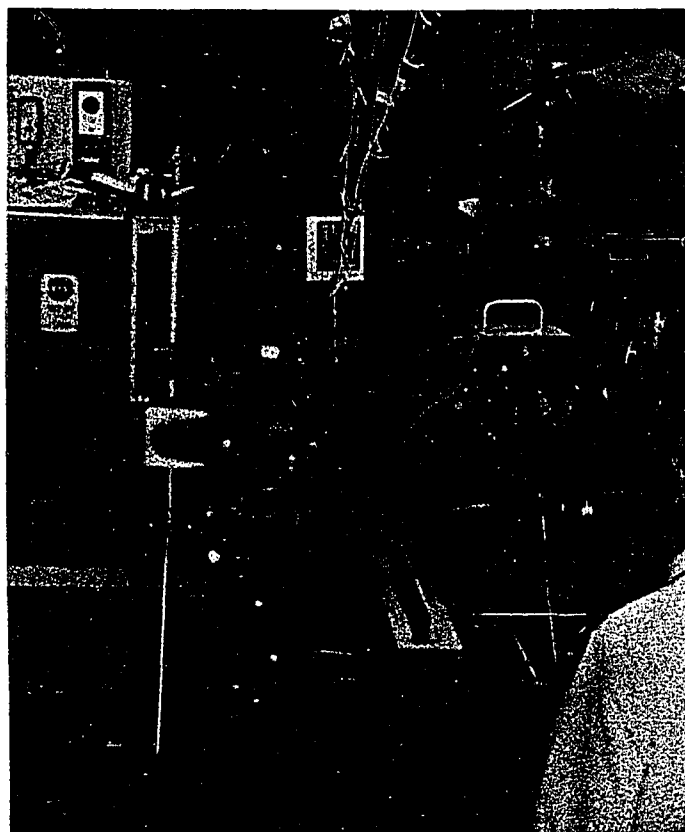
High speed photographic methods were first employed to provide records of the soybean stem cutting process. A "laboratory cutting analyzer" was assembled, utilizing the 22 in. diameter disc and variable speed DC drive motor of the centrifuge, Figure 68. One or two blades were mounted directly on the plate or onto force transducers bolted to the plate. The blades were mounted with a radial cutting edge, Figure 68 A and B. Blade speed was variable between 70 to 15,000 fpm (0.8 to 170 mph). Individual plants could be driven hydraulically or manually into the path of the blade on a carriage. Provision was made for the study of either



A. The 20° ramped blade mounted on a cutting force transducer element.



B. Plain smooth blade on transducer bolted to edge of rotatable disc.



C. The HYCAM 16 mm camera was operated up to 10,000 pps framing rate.

Figure 68. The lab cutting analyzer, utilized for counter-edge and impact cutting studies.

counter-edge or impact cutting. When the transducers were used, the force-time history of the cut was recorded from the four strain-gage full-bridge circuit via a four slip-ring connector to an Endevco signal conditioner and displayed on Visicorder chart or Tektronix storage oscilloscope. The resulting force records were found to be unreliable at speeds above 200 fpm, because the slip-rings generated a high level of noise. This extraneous signal was proportional to (speed)ⁿ and proved impossible to filter out at the higher speeds without destroying most of the desired signal (Table A-21).

In view of the difficulties attendant on measuring cutting force with this analyzer, and the expense involved in high-speed photographic studies of cutting, the idea of using "static" cutting simulation was considered. If the cutting process could be duplicated by drawing the blade slowly through the specimens in the Instron Testing Machine, Figure 70A, then considerable improvement in precision and ease of testing would be obtained.

The essential question was, does cutting speed affect the physical and mechanical properties of the bean stems? McKenzie considered this question in basic studies on wood cutting. He concluded that the counter-influencing effects of loss of strength due to local increase of temperature in the immediate area of cutting, and increase of strength with higher strain rates were approximately the same. Frictional forces during cutting were not significantly affected by tool speed. Under the controlled cutting conditions of his tests, he found that, with the exception of chip acceleration, the essential cutting process remained unchanged over a 300,000-fold range of cutting speeds (43).

A similar experiment was accordingly conducted on the Instron Testing Machine. The data are included in Table A-21 and summarized in Figure 69. Cutting force and energy were found to decrease at higher cutting speeds. To simulate the impact cutting action by a low speed test, information from the movie analysis was drawn upon and it was concluded that, in the initial stages of the cut, blade cutting at the middle of a two in. span fixed-ended beam would be appropriate. It was furthermore decided after initial counter-edge cutting trials, that 3/16 in. maplewood dowel could be used for more reproducible results on some aspects of the cutting phenomenon, Table A-22. In between the nodes, the soybean stem section consists of an approximately circular annulus of tough lignified material. Stem wall thickness near ground level is, between nodes, approximately one-fifth of diameter and the core is either hollow or filled with soft pith. Stems of average diameter 0.2 to 0.4 in. between nodes were chosen, and, in spite of the physical difference between the stem and dowel, the cutting behavior of the dry stems was found to closely parallel that of the 3/16 in. diameter dowel (compare Figures 70 B and E, right).

8.1.2 Typical counter-edge cut:

A chart record of a typical low stem cut with a medium sharp blade cutting against a model guard counter-edge is reproduced in Figure 71.

The cut proceeded as follows:

1. initial compression as blade penetrated stem
2. very slight flattening of stem. Occasionally longitudinal cracking occurred, but rarely to the extent of wall collapse, except for the thinnest-walled stems

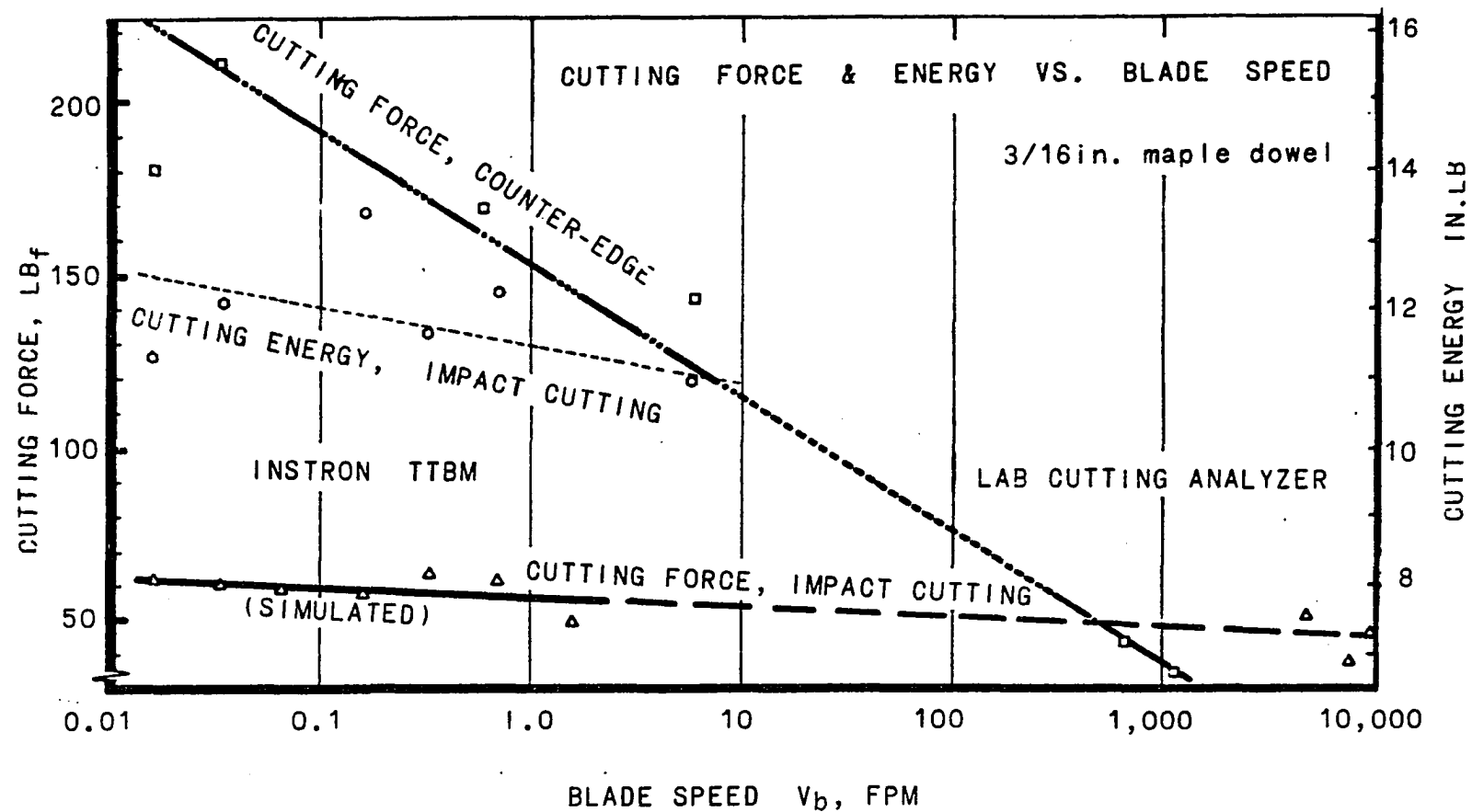
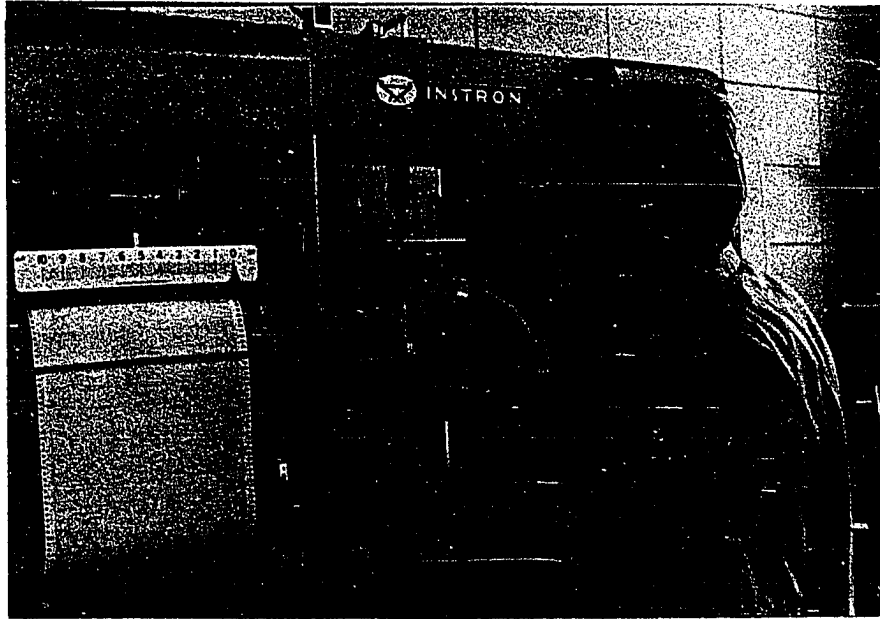
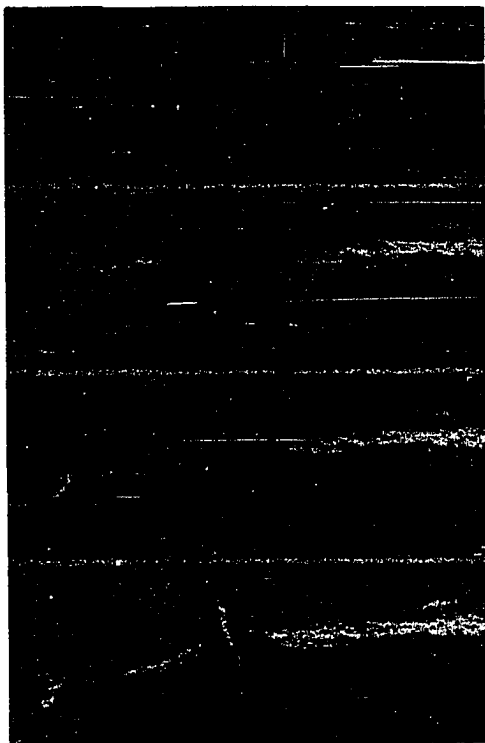


Figure 69. Influence on blade speed on cutting force and cutting energy. Medium sharp blade, 0.10 in. thick and 20° bevel angle, Instron and lab cutting analyzer tests.



A. Instron TTBM Tensile Testing Machine, 0-500 kg capacity.



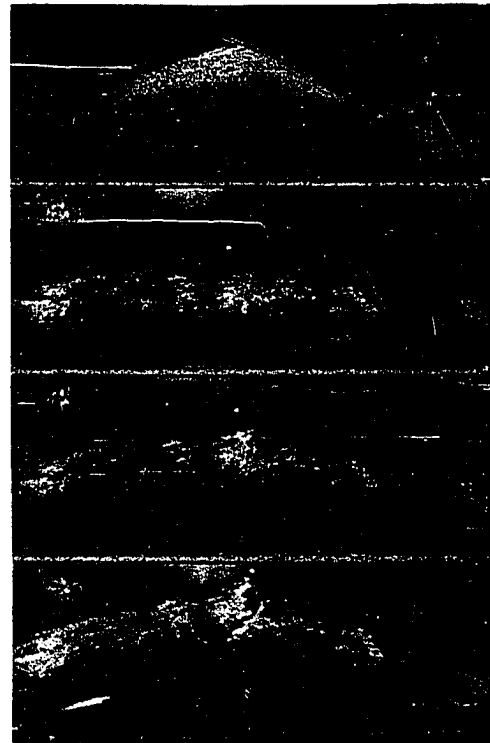
Counter-edge cutting

B.

C.

D.

E.



Impact cutting simulation

Figure 70. Stem cutting analysis on the Instron Testing Machine.

3. sometimes failure occurred first along a plane inclined approximately 45° to the stem fibers
4. cracking ahead of the blade preceded shear failure as blade penetrated almost through the stem
5. as the blade approached close to the counter-edge, the force level dropped. Secondary and tertiary failure planes appeared and chips began to form as stem pieces were "hairpinned" into the guard space
6. force increased again following severance as friction was generated by blade and chips competing for space under the guard lip. Counter-edge cutting forced the blade slightly away from the ledger, due to the lack of rigidity of the model on the Instron
7. there was a strong force tending to eject the top of the severed stem piece out from the guard.

8.1.3 Influence of blade sharpness on counter-edge cutting:

Sharpness of the blade was measured by the radius of the (rounded) tip of the blade. A dull blade used more energy in cutting, created larger chips, and exerted a higher force, Figure 71.

Table 27. Effect of blade sharpness for 0.1 in. thick 20° bevel angle blades in orthogonal counter-edge cutting of Amsoy stems between nodes^a.

Blade	Tip radius (sharpness)	Mean peak cutting force	Mean energy
	mm	lb.	in. lb.
Sharp	0.06	44.73	2.89
Medium sharp	0.25	49.50	3.19
Dull	0.50	62.48	3.26

^aBlade speed was 1 cm/min on Instron TTBM. Each result represents 4 tests on Amsoy stems of mean diameter 0.22 in., 9% MC.

AMSOY SOYBEAN STEM CUTTING AGAINST DOUBLE COUNTER-EDGE

LOADING RATE (BLADE SPEED): 1 CM/MIN; INSTRON TTM;

CHART SPEED : 10 CM/MIN; 50 KG SCALE;

STEM MOISTURE: APPROX. 9% W.B.

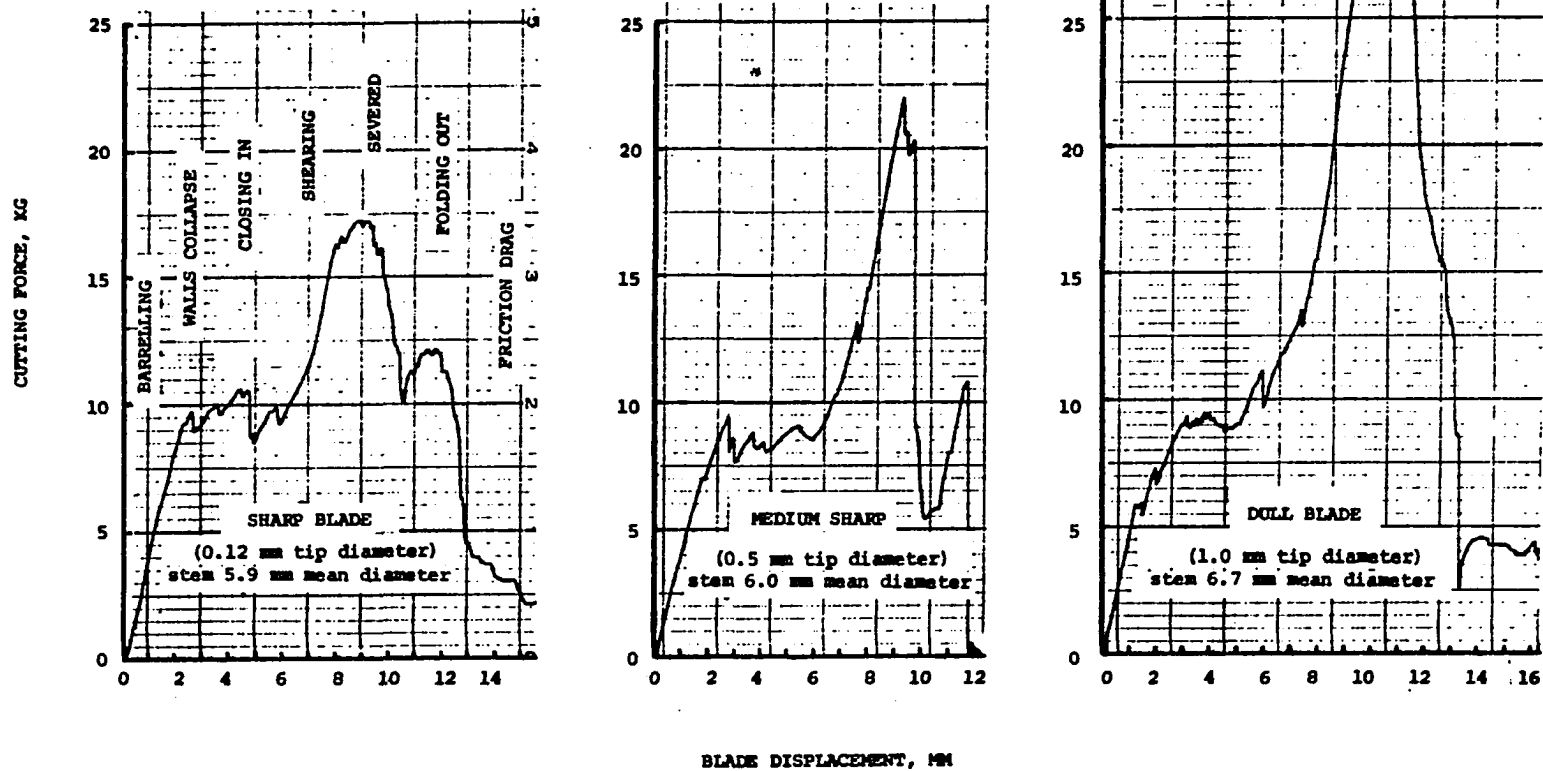


Figure 71. Facsimiles of the Instron recording chart force/displacement results for the counter-edge cutting of Amsoy stems.

8.2 Comparative Cutting Forces with Actual Counter-Edge Cutterbars

8.2.1 Field measurements: Case 1070 combine:

Forces were measured in the knife head of a Case 1070 combine using strain gage readouts as follows¹:

Table 28. Forces encountered by standard 2-3/4 in. stroke^a, 3 in. guard, Case 1070 13-ft combine, traveling at 3 mph in soybeans at 500 rpm crank speed.

Load situation	Recorded loading, tension or compression, lb.
Unloaded, running empty, peaks	140
Field operation at 3 mph in soybeans	250 - 300 ^b
Peak force value required to cause initial stall of sickle (measured in cereal grain)	to 900 ^c

^aThe 2-3/4 in. stroke was less than guard pitch (3 in.). Knife stroke "grows" when operating, due to normal clearances, wear and elasticity in the assemblage.

^bWith the knife in register, the stem cutting action occurs simultaneously across the header.

^cKnife wear and fatigue were said to be limiting the speed of operation of the combine cutterbar to less than 500 rpm crank speed.

8.2.2 Counter-edge cutterbar model with plain and serrated blades:

Results from tests in 1968 with a small hand-operated cutterbar with standard ledgers are plotted in Figure 72, along with the cutting force vs. stem diameter tests from the Instron in 1971. Variety Amsoy stems cut

¹Evans, Tom. J. I. Case Co., Bettendorf, Iowa. Model 1070 combine component power evaluations. Private communication. March 14, 1968.

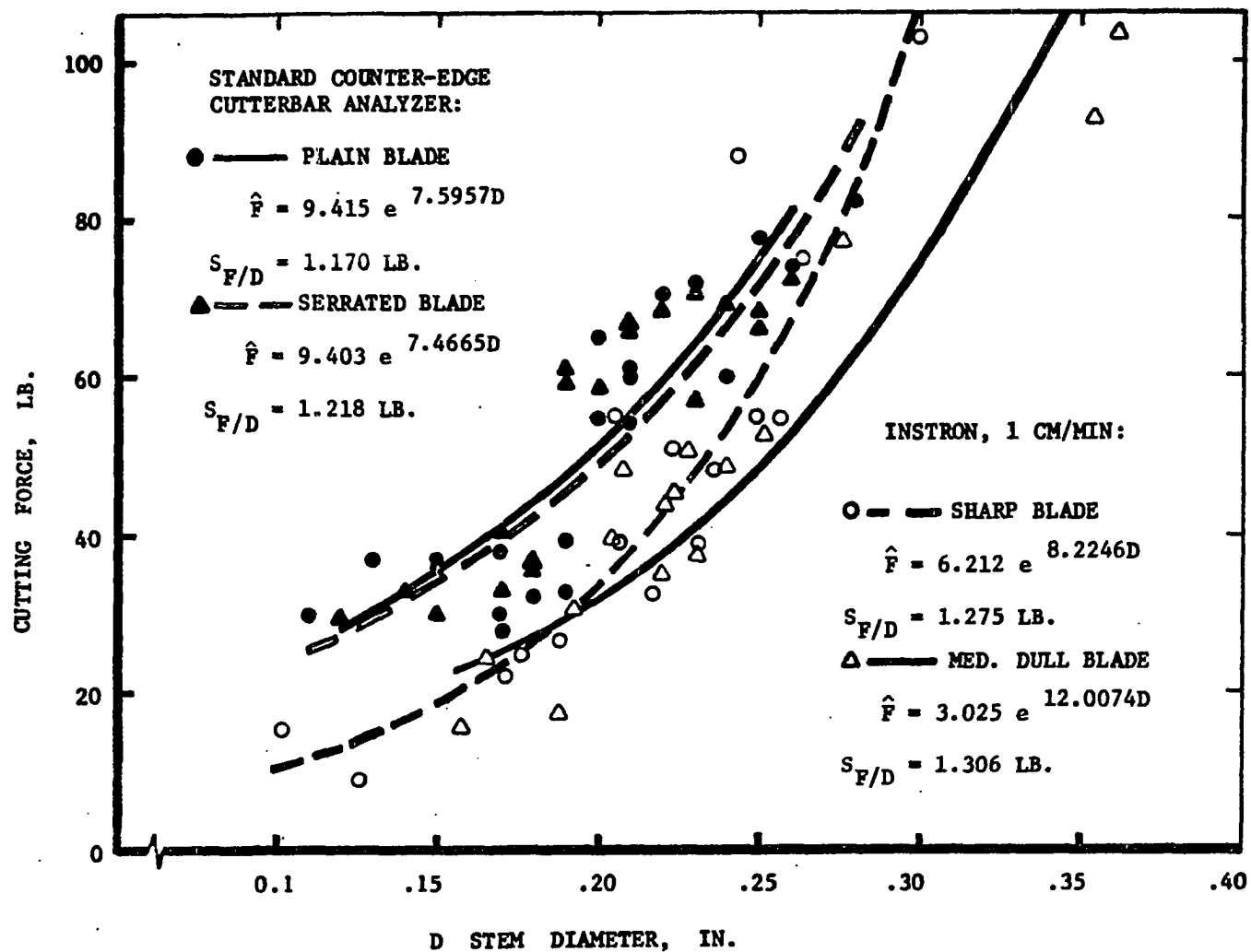


Figure 72. Counter-edge cutting of Amsoy stems on cutterbar model and on Instron. Cutting force vs. stem diameter, between nodes.

between nodes.

The plain (smooth) blade was found to require a slightly higher cutting force than the serrated blade.

8.3 Impact Cutting Forces

A flexible plant stem is accelerated by the impacting blade before being severed. The blade can impart a considerable amount of energy to the severed stem-piece. Feller analyzed impact cutting of alfalfa, and observed cases where 18 in. long stalks, 1/8 in. diameter and cut 3 in. from the base, were thrown 15 ft when cut by a sharp blade traveling at 1900 fpm. The lower part of the stem moved faster, so that the stalk approached the horizontal position during flight (18).

The energy in excess of that required for cutting could not be assessed by the Instron low speed simulation method previously outlined. The cutting force history for Amsoy "impact" cutting was recorded in Figures 70 C to E, right. A chart record of a typical stem cut with the medium sharp blade at the middle of a two in. span stem glued into wooden mountings is reproduced in Figure 73.

Compare the simulated impact cutting behavior of Figure 70 with the high-speed movie records of actual impact cuts as seen in Figure 74. There was a reasonably good correspondence in the model behavior. The stem impact cut (between nodes) simulated on the Instron proceeded as follows:

- (1) initial bending with only slight impression of blade into stem, with up to 1/2 in. bending deflection (the deflection was somewhat less in the actual high speed cutting situation)

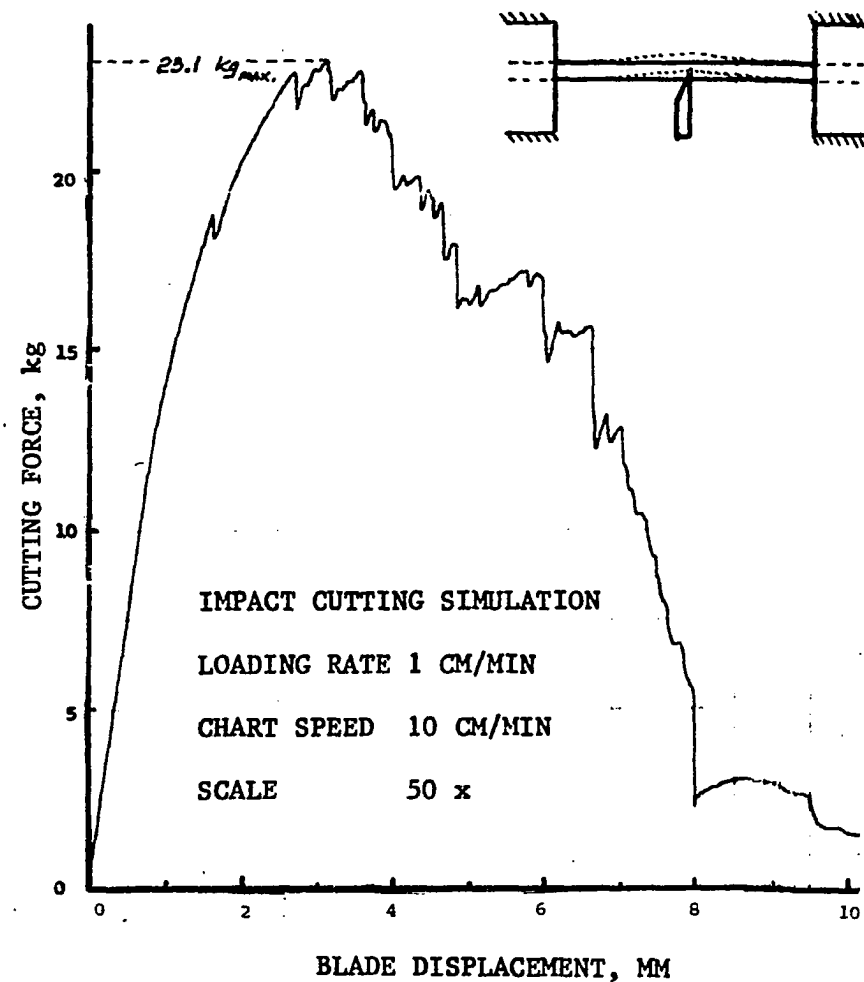
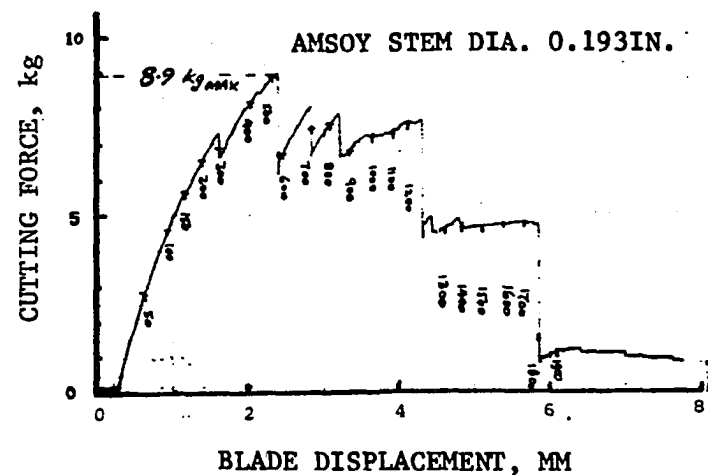
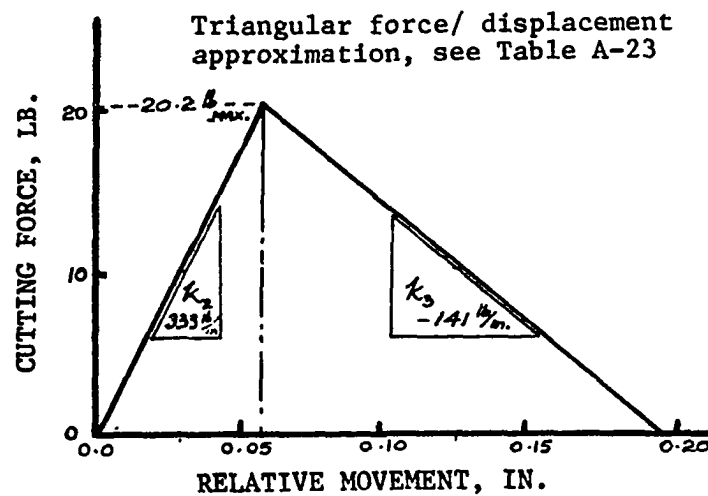


Figure 73. Reproductions of charts from Instron "impact" cutting tests on an Amsoy stem, left, and on a 3/16 maplewood dowel, right.

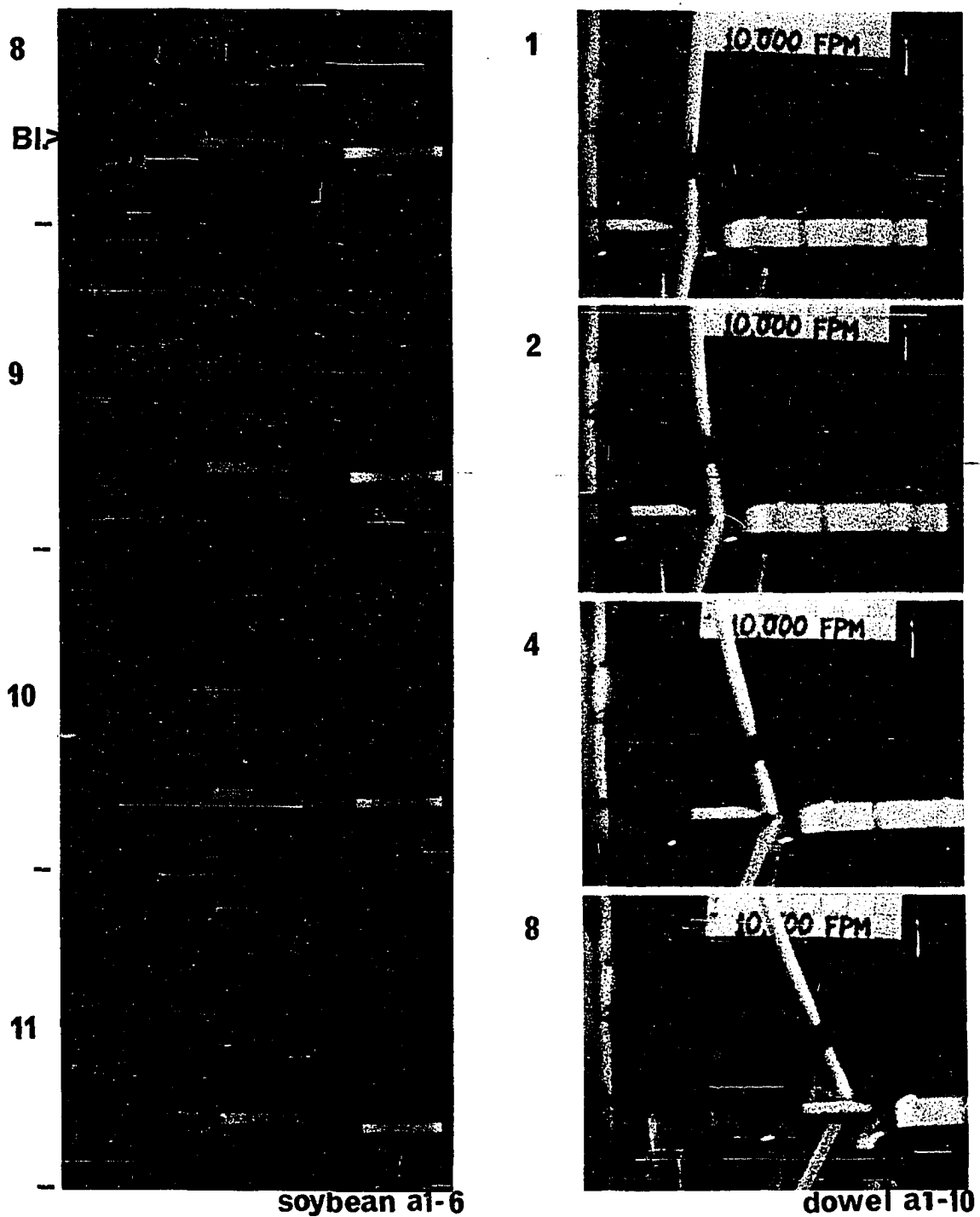


Figure 74. Enlargements of selected 16 mm movie frames taken at 10,000 pps framing rate of the impact cutting of an Amsoy stem and a 3/16 in. diameter dowel in the cutting analyzer.

- (2) when sufficient bending resistance was encountered, the blade began to penetrate to about 1 mm (0.04 in.) depth as bending continued
- (3) at this depth the remainder of the stem (or dowel, which behaved similarly) would crack, as a failure zone proceeded ahead of the blade
- (4) practically no flattening or longitudinal cracking occurred on thick stems
- (5) no further compressive effects were observed in the stem as the blade advanced through the crack
- (6) some longitudinal splitting or splintering accompanied the movement of the blade as it proceeded past the half way mark.

The inertia of the ends of the plant provided the "fixed end reaction," as simulated by the wooden blocks clamped on the Instron. At blade speeds of 6,000 to 10,000 fpm the stem was severed within the first two or three frames in the sequence, i.e. within 0.0003 sec, or in a distance of usually less than 3/8 in. of blade travel. The blade would continue to exert an influence on the severed stem for the next 6 to 30 frames, depending on blade thickness and bevel angle. An attempt was made to predict from theory and a knowledge of stem properties the behavior of the stem during impact cutting. Table A-23 and Figure 106.

If the blade was dull and speed too low, the stem was bent over by the blade until base-breakage occurred (or the plant was pulled out of the "ground," or clamp). Blade sharpness did not affect impact cutting force to the same extent as it did with counter-edge cutting. It was

observed however, that the sharper the blade, the lower was the velocity required to produce a clean cut by impact. With the dull blade this minimum speed was approximately 4,500 fpm on the cutting analyzer; with the medium sharp blade, base breakage did not occur until the blade was slowed down to below 3,500 fpm.

8.3.1 Relationships between cutting action and shatter:

Several authors have stated that the vibrating action of the reciprocating cutterbar caused soybean shatter (17, 38, 49), and it was suggested that there would be a direct relationship between cutting force or energy and degree of shatter of pods adjacent to the blade. The results from the cutting analyzer recorded in Table A-24, and reproduced in Figure 75, proved otherwise. These tests were conducted by using plants pulled from the field, stored and, when needed for testing, carefully trimmed of all pods up to 1 in. above the 4-1/2 in. cutting height. Thus the blade never actually touched the pods during cutting. Ten plants were cut at each speed setting and advance rate was less than 1 mph. The results are summarized as follows:

8.3.2 Counter-edge cutting:

- (1) Cutting with a standard reciprocating cutterbar, even at peak blade speed (392 fpm, midway between guards) was unlikely to be responsible for measurable shatter. Even with the blunt blade, only an occasional pod shattered at speeds below 400 fpm. In the field, the partially dehisced pods would be possible candidates for shatter, but the bundles used in the lab were divested of any partially dehisced pods before testing.

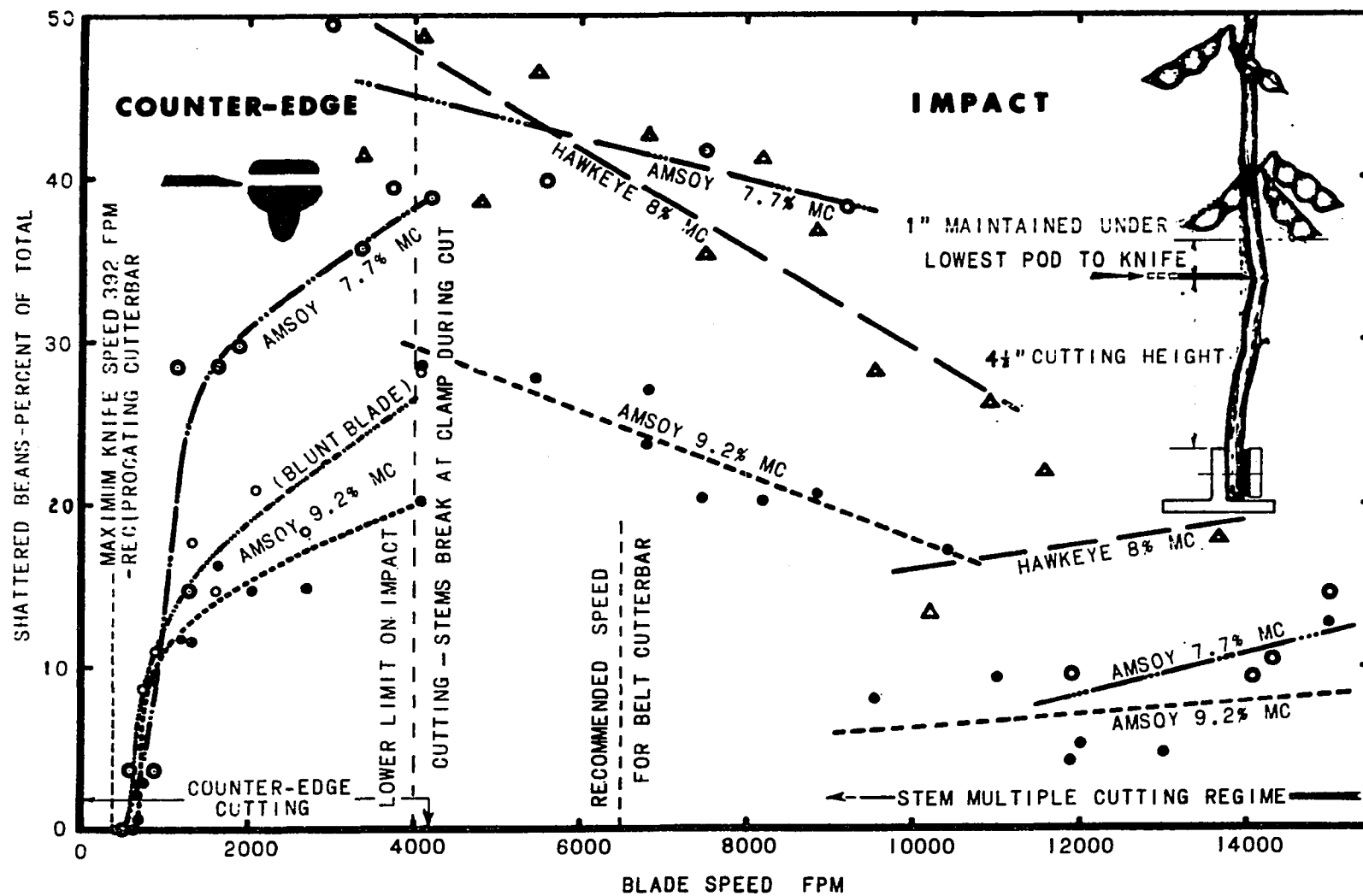


Figure 75. Influence of cutting blade speed on indirect shatter.

- (2) At speeds above 400 fpm, depending upon moisture content, shatter loss climbed rapidly with blade speed for counter-edge cutting.
- (3) A dull blade and lower moisture contents caused increased shatter as blade speed increased above 400 fpm.
- (4) The slope of the shatter loss curve declined at speeds above 1000 fpm.

8.3.3 The single impact cut:

- (1) Impact cutting was possible at speeds above 3,000 fpm with a medium sharp blade (4,500 fpm with a dull blade). At lower speeds stems tended to break at the base.
- (2) Shatter loss was severe with impact cutting but declined gradually with increasing blade speed, up to 12,000 fpm.
- (3) An independent test, at a blade speed of 7,000 fpm, was run to determine the influence on shatter of distance of the pod from the blade. Shatter diminished very gradually with distance from the blade for single impact cuts. It was noted, incidentally, that the thickest stems had somewhat more shattered pods than thinner stems. Stems of equal diameter, but with more pods, tended to have less shatter than stems with very few pods.
- (4) Shatter loss increased with diminishing moisture content.
- (5) For single impact cuts, shatter loss may be related to cutting force. Further work is necessary to confirm this relationship.

8.3.4 Stem cutting by multiple impacts:

At blade speeds above 9,000 fpm, some stems received multiple cuts before severance. One stem was observed on movie film that was cut after two slices by a blade traveling at 10,000 fpm. No pods were shattered on this stem. In Figure 75, the results were scattered at the highest blade

speeds because some stems were cut in a single impact, with high shatter; while others were multiple cut, with no shatter. Nevertheless, shatter loss appeared to be increasing with speed in the multiple cutting regime.

8.4 Severed Stem Motion After Cutting

The amount of energy imparted to the severed stem-piece depends upon a variety of factors. Bledsoe (5) tabulated the work on stem cutting of Feller, Chancellor and McClelland and suggested that energy transfer was increased by

- increasing knife velocity
- increasing height of cut (i.e. shortening of the severed piece)
- cutting heavier stems
- varying knife angle
- using dulled blades.

Movie and stroboscopic photo-instrumentation was used to record the trajectory of stems severed by

- (a) a standard reciprocating cutterbar (without influence of the reel)
- (b) a pendulum mounted low-speed cutter, with counter-edges of various shapes
- (c) a continuous chain cutterbar, cutting against various cutting edges
- (d) impact, using two blade shapes (plain 20° and ramped 20° bevel), see Figures 68 A and B.

The computer program of section 5.9 was used in the determination of the absolute displacements, velocities and accelerations of points on stems for several cutting situations (see Table 29).

Figure 76 shows line drawings traced and reduced from projected

Table 29. A scale of representative peak acceleration values, computed from film records of several cutterbar designs. Cutting of Amsoy stems on the lab cutting analyzer.

Cutting situation	Acceleration, G's
1. <u>Reciprocating cutterbar</u> (500 rpm)	
(a) Maximum blade acceleration for reciprocating knife as a slider crank mechanism	21.4
(b) Point on stem near cutterbar following contact with ledger	210
2. <u>Continuous chain cutterbar</u> (600 fpm) ^a	
Point on stem near blade of chain cutterbar, during contact with blade	572
3. <u>Centrifugation</u> ^b	
10% of pods shattered at 9.9% MC	295
4. <u>Impact cutting</u> , 7,500 fpm	
(a) Point on stem near blade	21,420
(b) Point on stem 3/4 in. from blade (data in Fig. 77)	15,530
5. <u>Impact Cutting</u> , 10,000 fpm	
(a) Point on stem near blade	23,700
(b) Point on stem 4 in. from blade, near pod/stem junction	14,200
(c) Cutting 3/16 in. dowel, point near blade	35,300

^aAt a given blade speed, variations in the profile of the counter-edge and blade angle were observed to have an effect on the ability of the knife to initiate cutting and on the degree of sliding at the blade, but the trajectory of the plant after severance was not markedly affected by the counter-edge shape or blade angle.

^bAn acceleration field of approximately 300 G's was the estimated level for indirect shatter to occur in 10% of the pods attached to a stem being cut. This figure (300 G) does not apply to a pod directly struck by cutting elements.

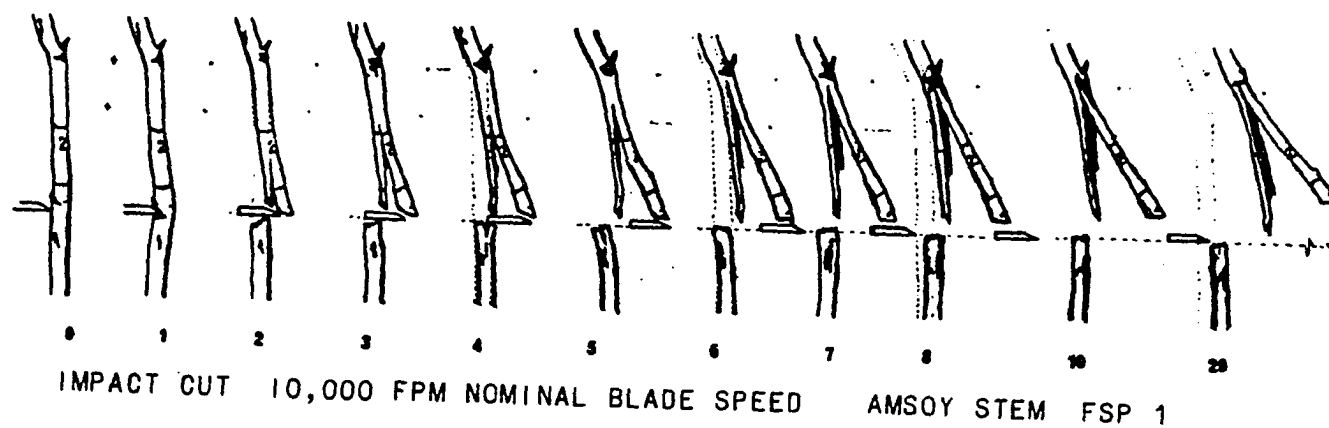
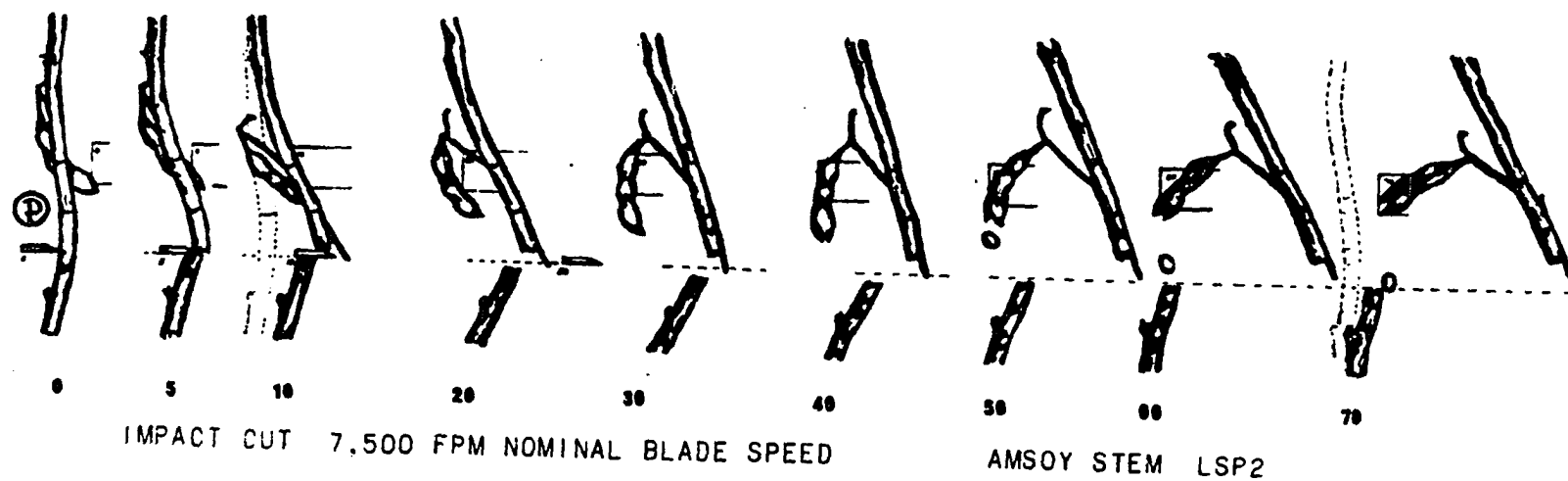


Figure 76. Behavior of Amsoy stems cut by a single impact at 7,500 and 10,000 fpm nominal blade speed.

images of the cutting of stems single-cut by an impacting blade traveling at (A) 7,500 fpm (85 mph) and (B) at 10,000 fpm (114 mph).

The point P on the stem cut at the 7,500 fpm blade speed was studied in detail. It is this point for which the computed displacement, velocity and acceleration vs. elapsed-time record is displayed in Figure 77. A superimposed lateral vibration (in the bending mode) was clearly discernible on the film, as the severed stem piece separated from the blade. The maximum frequency of this vibration was estimated to be approximately 2,500 Hz. Maximum computed velocity and acceleration for point P on the stem was 5,735 fpm and 15,531 G's, respectively.

In Figure 78 the essential difference between the trajectories of a stem cut by impact and by counter-edge cutting is illustrated. The trajectory of the severed stem piece was largely governed by type of cut, blade speed, position of center of gravity and blade direction. Note the relatively small amount of movement of an impact-cut stem during the cut. This was indicative of low stem slippage and therefore shorter stubble lengths.

8.5 Stem Motion Before Severance with the Standard Reciprocating Cutter-bar

In Figure 79 the various stem angles and cutterbar relationships are delineated. Assume, for simplicity, a simple harmonic motion of the blade with respect to the platform, see Figure 80. Cutterbar advance ratio was defined as

$$\pi_3 = \frac{\text{mean lateral knife speed}}{\text{combine forward speed}} \quad (8-1)$$

$$= \frac{2S'N}{V} \quad (8-2)$$

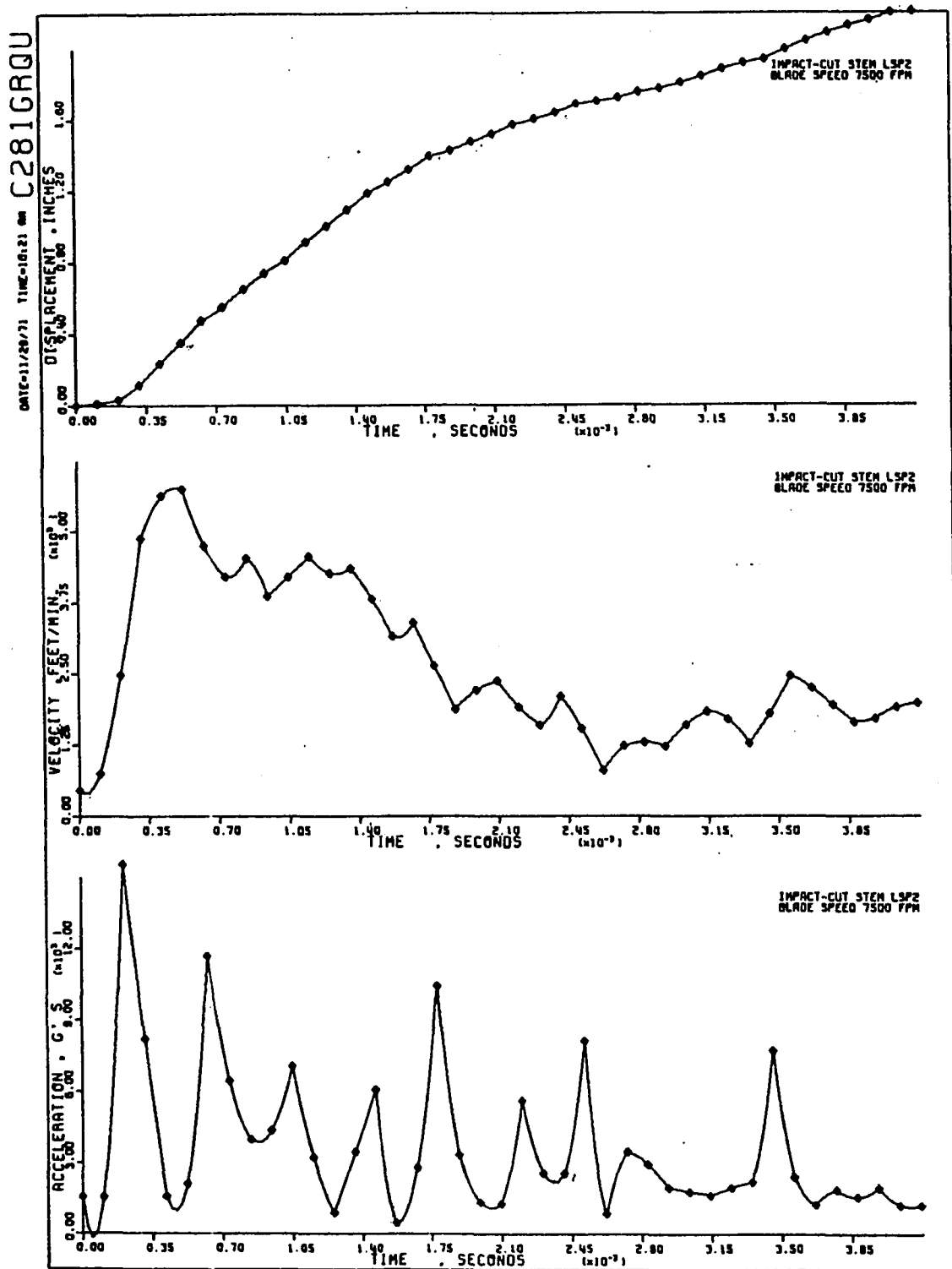
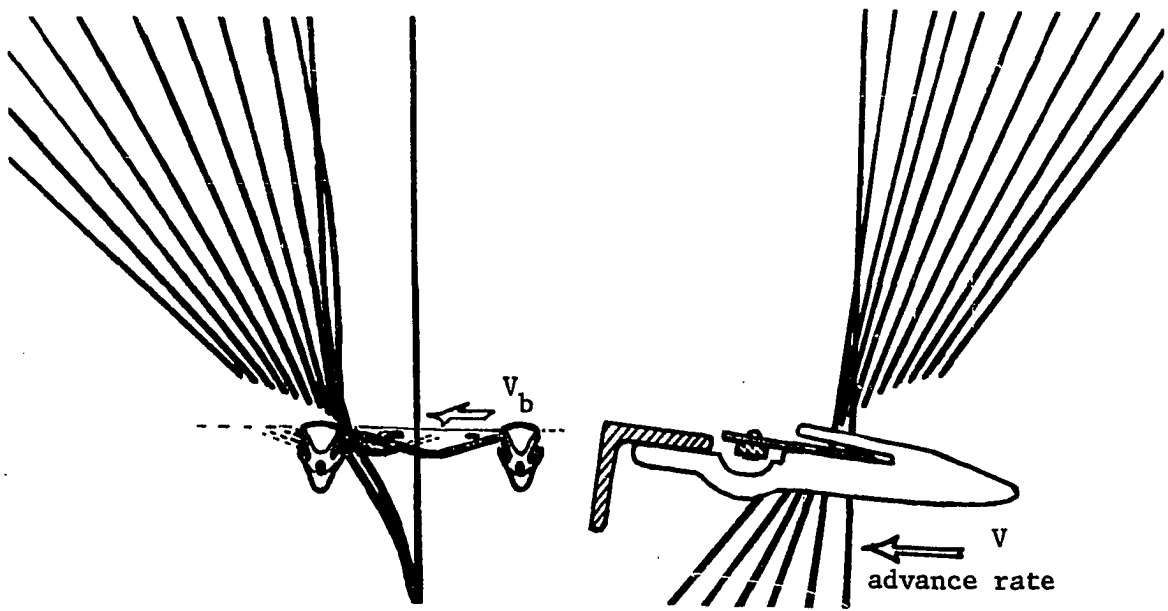
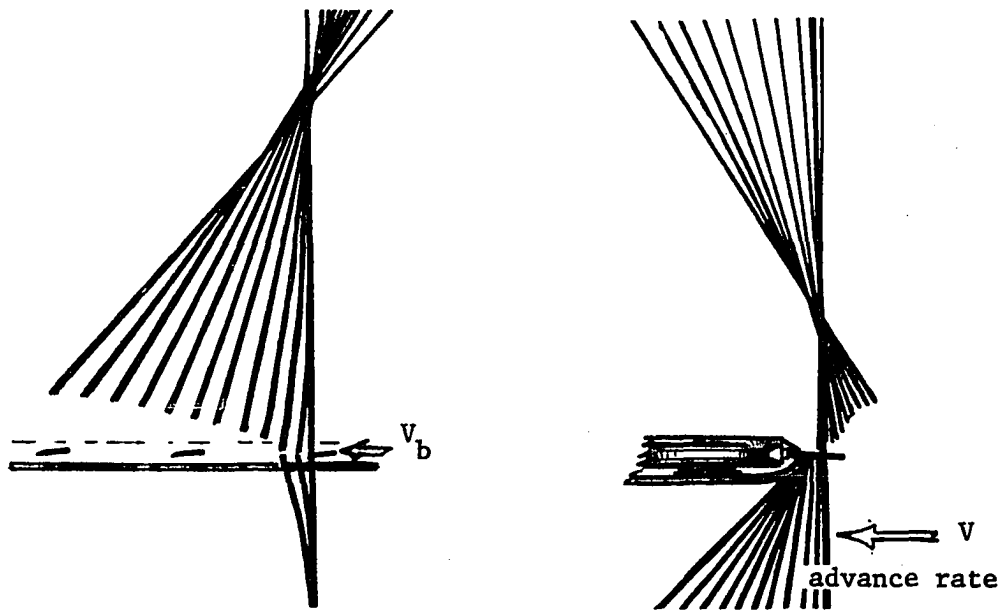


Figure 77. Computer plots of displacement, velocity and acceleration vs. time for a stem cut by single impact by a blade traveling at 7,500 fpm.



A. Front and side views, counter-edge cutting $\pi_3 = 1.0$.



B. Front and side views, single impact cut $\pi_3 = 20$.

Figure 78. Typical behavior of stems following severance. A. Counter-edge cutting with reciprocating cutterbar; B. single impact cut.

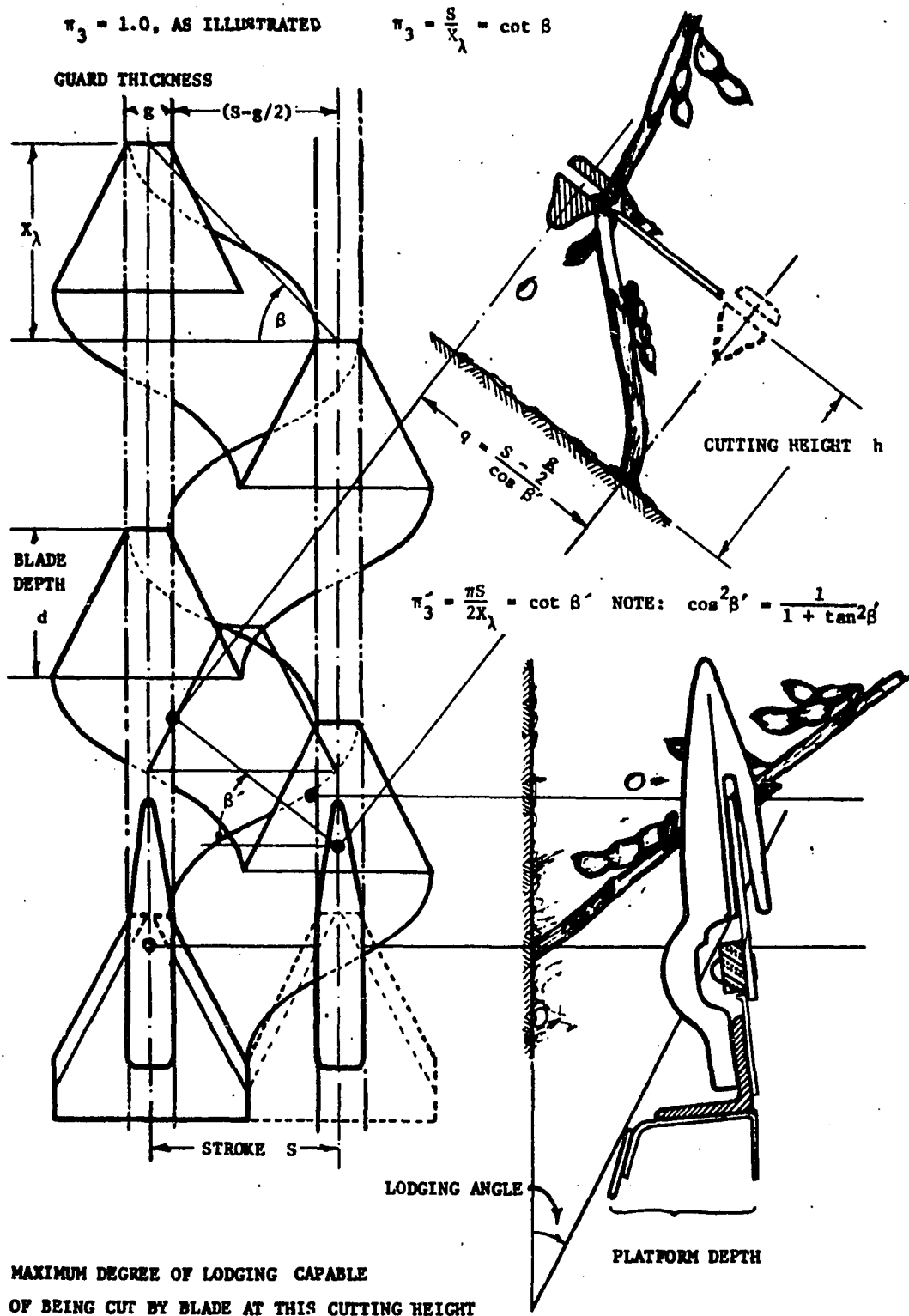
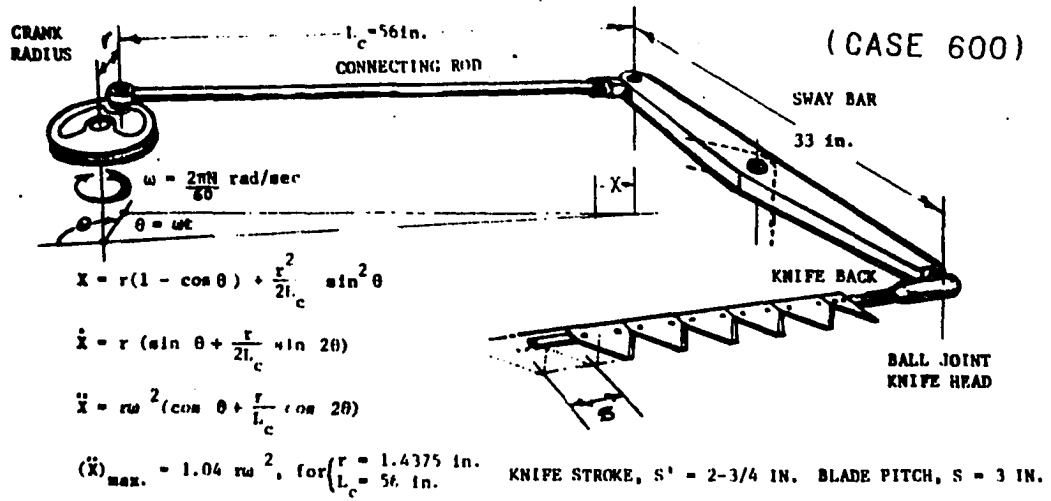


Figure 79. Plant stem and reciprocating cutterbar relationships.



COMBINE CUTTERBAR DRIVE MECHANISM

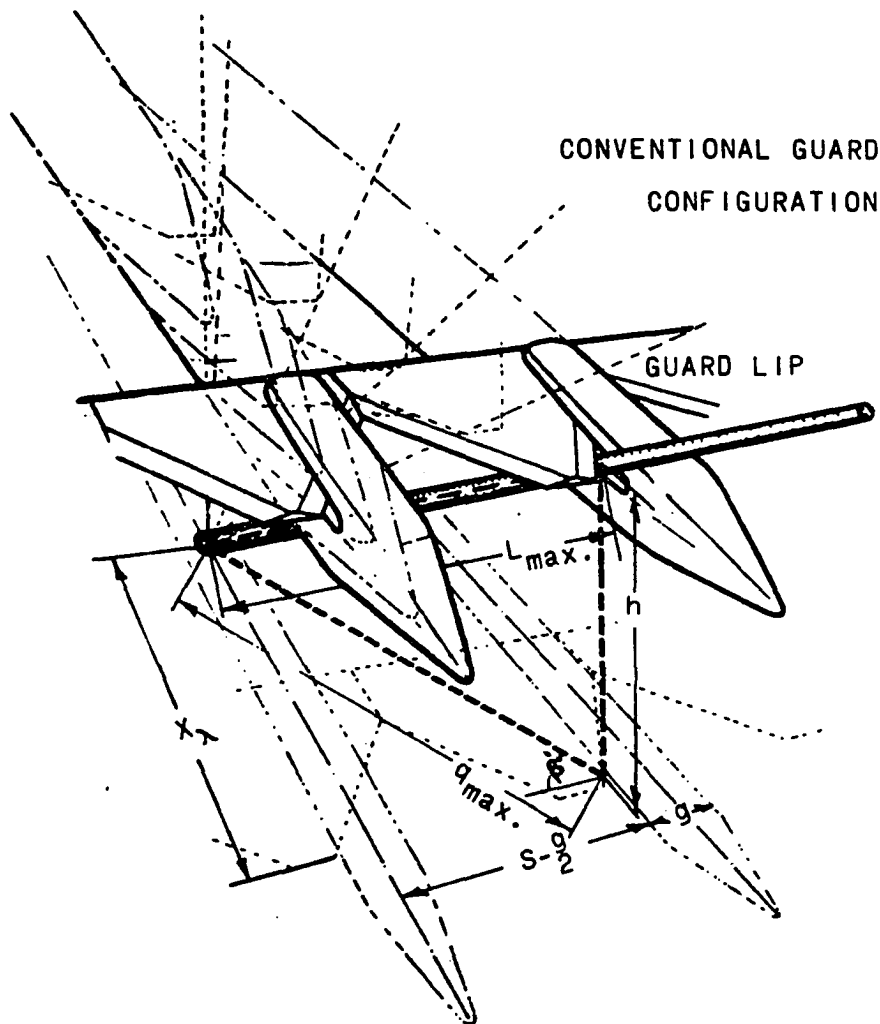


Figure 80. Factors influencing stubble length, standard cutterbar.

i.e.

$$\pi_3 = \frac{S'}{X_\lambda} \quad (8-3)$$

where V = combine forward speed, fpm

S' = cutterbar nominal stroke, ft

S = actual guard pitch, ft

X_λ = cutterbar advance at speed V fpm, during one stroke, ft

i.e.

$$X_\lambda = \frac{V}{2N} \quad (8-4)$$

With the standard cutterbar

$S' = 0.229$ ft and $N = 500$ rpm

i.e. Mean lateral knife speed = 229 fpm

Now $\pi_3 = 1.0$ when $V = 229$ fpm (2.6 mph)

Referring to Figure 80, the maximum theoretical stubble length is found from the equations:

$$q_{\max} = \left(S - \frac{g}{2}\right) \sqrt{1 + \left(\frac{X_\lambda}{\pi r}\right)^2} \quad (8-5)$$

and if

$$2r \approx S$$

then

$$q_{\max} = \left(S - \frac{g}{2}\right) \sqrt{1 + \left(\frac{V}{2NS}\right)^2} \quad (8-6)$$

and

$$l_{\max} = \sqrt{h^2 + q_{\max}^2} \quad (8-7)$$

Thus maximum stubble length is a function of cutterbar stroke S , guard thickness g , reciprocating frequency N , cutting height h , and combine speed V .

$$\text{Maximum stem slippage} = \ell_{\max} - h \quad (8-8)$$

Example: Cutting soybean stems at 4 in. cutting height and 3 mph, i.e.

$$h = 0.33 \text{ ft}, S = 0.25 \text{ ft}, g = 0.0625 \text{ ft}, N = 500 \text{ rpm},$$

$V = 264 \text{ fpm}$, and assuming that the stem does not slip along the blade in the horizontal plane

$$q_{\max} = 0.318 \text{ ft (3.82 in.)}$$

$$\ell_{\max} = 0.460 \text{ ft (5.53 in.)}$$

i.e.

$$\text{Maximum stem slippage} = 1.53 \text{ in.}$$

Whether lateral stem slippage will occur before cutting depends upon friction angle between stem and blade edge, blade angle, amount of crowding (governed by advance ratio), cutting height, degree of lodging, and stem rigidity. High-speed photographic studies by Johnston (33), with grass stems, showed that very little blade to stem slippage occurred along the blade edge before stem meets ledger, until a critical feeding rate was exceeded. At higher crowding rates it was found that stem sliding occurred toward the front of the knife section; this caused large longitudinal stalk bending. The same condition in soybean harvesting leads to branches and lodged stems not being cut, but forced to slip under the knife. At excessively high forward speeds, and lower crowding rates, rearward slippage along the blade can occur. Platform depth governs the minimum stem lodging angle which will allow stem cutting to occur at a given height, Figure 79.

When the stem meets the ledger, the included angle between knife and counter edge ("pinching angle") becomes important, Figure 81. For maximum

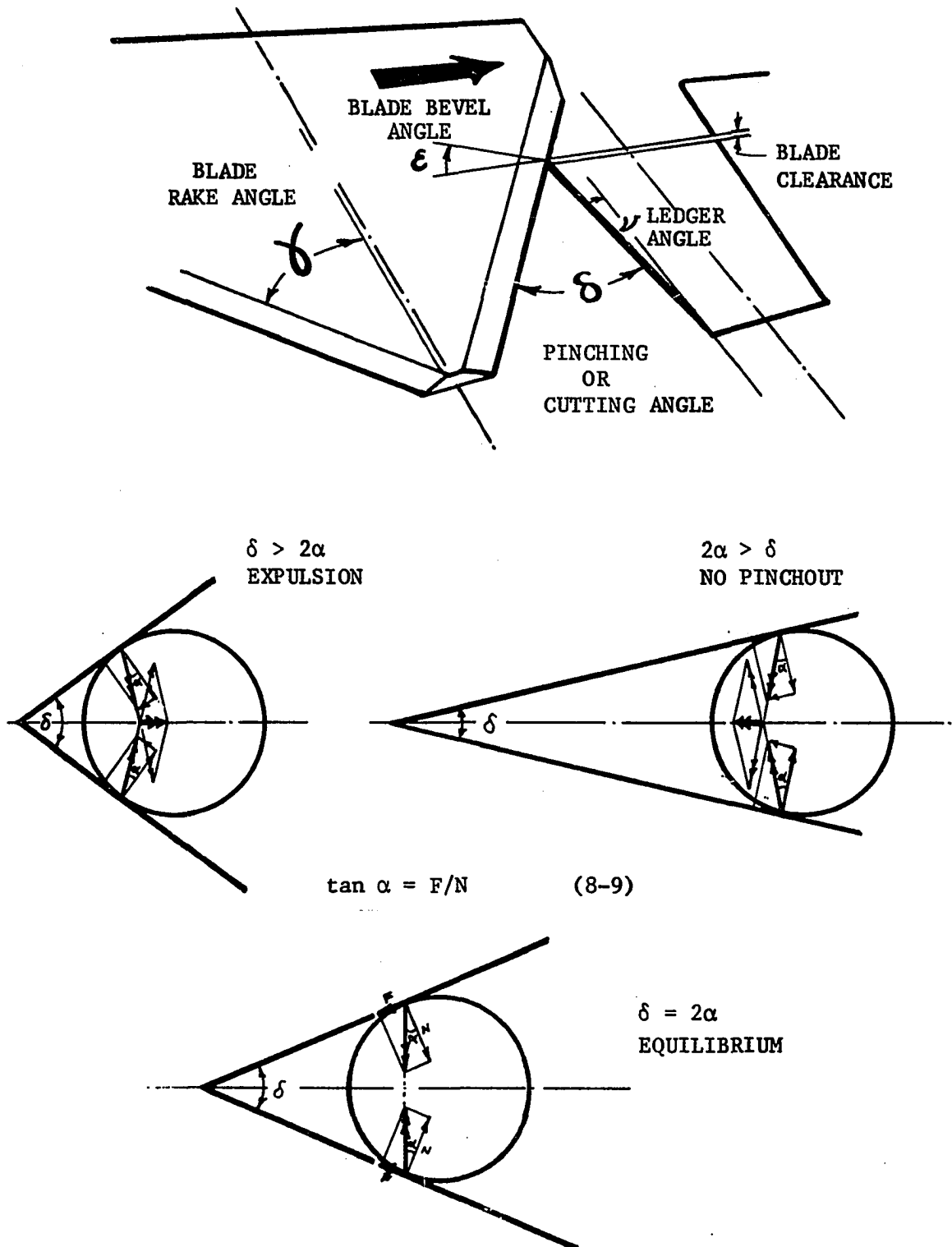


Figure 81. When stem meets ledger during counter-edge cutting.

feeding, this angle should be as large as possible. But beyond a certain angle, stem pinch-out will occur. This pinching angle must be less than twice the friction angle (2α) for zero slippage of a freely suspended stem. When bending stiffness and plant inertia are accounted for, the previous maximum angle, 2α , may be exceeded. Combine cutterbars typically have a blade rake angle $\gamma = 30^\circ$ to 35° (6), and a blade bevel, or sharpening, angle of 20° , Figure 81. Friction angle for dry soybean stalks was found to be about 18° with a smooth blade and ledger.

8.6 Factors Influencing Stubble Length - Reciprocating Cutterbar

Figure 82 illustrates a "stem crowding" diagram and a stubble profile obtained from closely spaced plastic sticks cut in the lab test stand.

A consideration of those factors influencing stubble length pointed clearly to the conclusion that anything that increased stubble length would markedly increase header losses (Figures 23 and 54). The effect of the following variables on stalk slippage and stubble length was measured and illustrated.

8.6.1 Reel index, Figure 83:

At the given forward speed, 2.5 mph, reel speed variations exerted a small but predictable influence on stem slippage. Hollow plastic sticks, as seen in Figure 54, were used as plant models in this lab test. The retarding influence of underspeeding the reel caused a materially increased stubble length.

8.6.2 Cutterbar frequency, Figure 84:

As cutterbar speed was diminished below the standard setting, the resultant increased crowding against the guards led to a rapid increase in

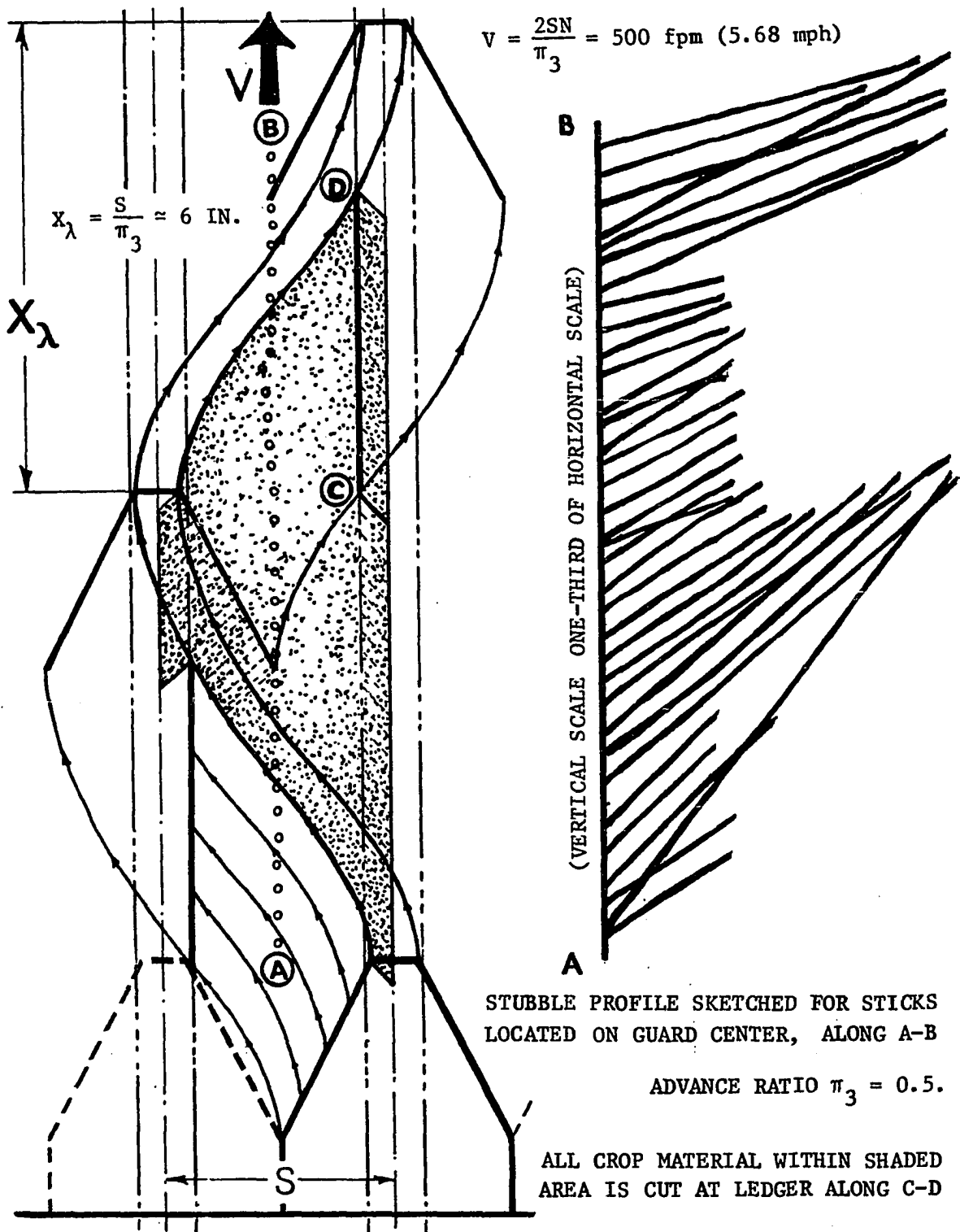


Figure 82. Stem crowding diagram and actual stubble profile measured in a header lab test.

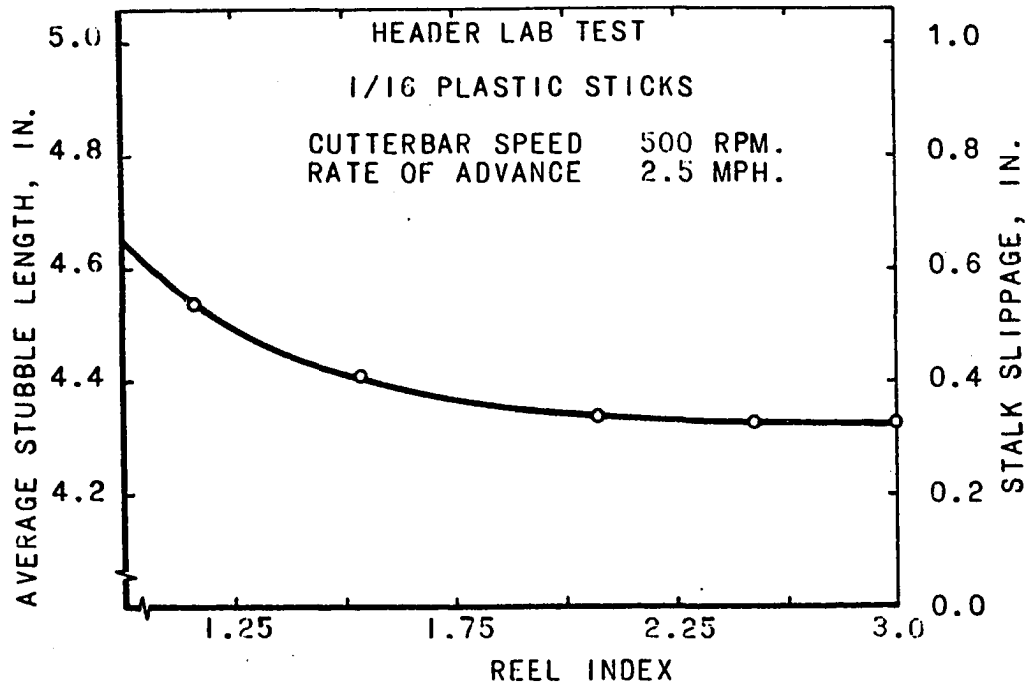


Figure 83. Influence of reel index on stubble length.

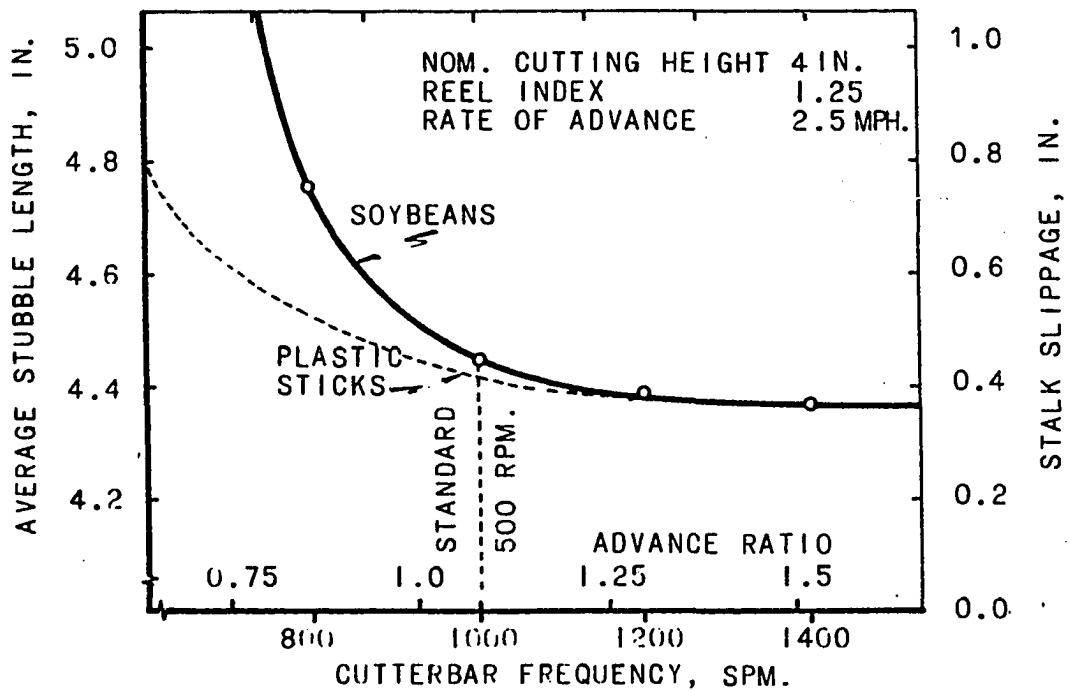


Figure 84. Influence of cutterbar speed on stubble length for a given forward speed, etc.

stubble length.

8.6.3 Rate of advance, Figure 85:

The effect of increasing forward speed at a given knife speed was substantially the same as varying the knife speed at a fixed forward speed; the knife becomes over-crowded at advance ratios below 1.0.

8.6.4 Cutting height, Figure 86:

At the lowest cutting heights, the maximum lateral deflection of the stems and slippage increased as predicted in Equations 8-6 and 8-7. Note the stubble profile in Figure 53, right.

8.7 Influence of Cutterbar Speed on Header Losses

The results of this lab test, plotted in Figure 87, were obtained from runs at 2.5 mph with a standard cutterbar, but with the auger and reel removed and replaced by the air jets and fan as was shown in Figure 53, left (Data in Table A-25).

The prediction equation for Total Header Loss $\hat{\pi}_1$ vs. Cutting Speed N had the form:

$$\hat{\pi}_1 = \frac{2.7735 \times 10^5}{N^2} + 1.1404 \times 10^{-5} N^2 \quad (8-10)$$

$$S_{\pi/N} = 0.9247, R^2 = 0.9846,$$

or in terms of advance ratio π_3 :

$$\hat{\pi}_1 = \frac{1.4320}{\pi_3^2} + 2.2081 \pi_3^2 \quad (8-11)$$

which results in optimal operation at an advance ratio of 0.897.

Again, the marked effect of increasing advance ratio on increasing shatter loss is seen, denoting the effects of individual separation of

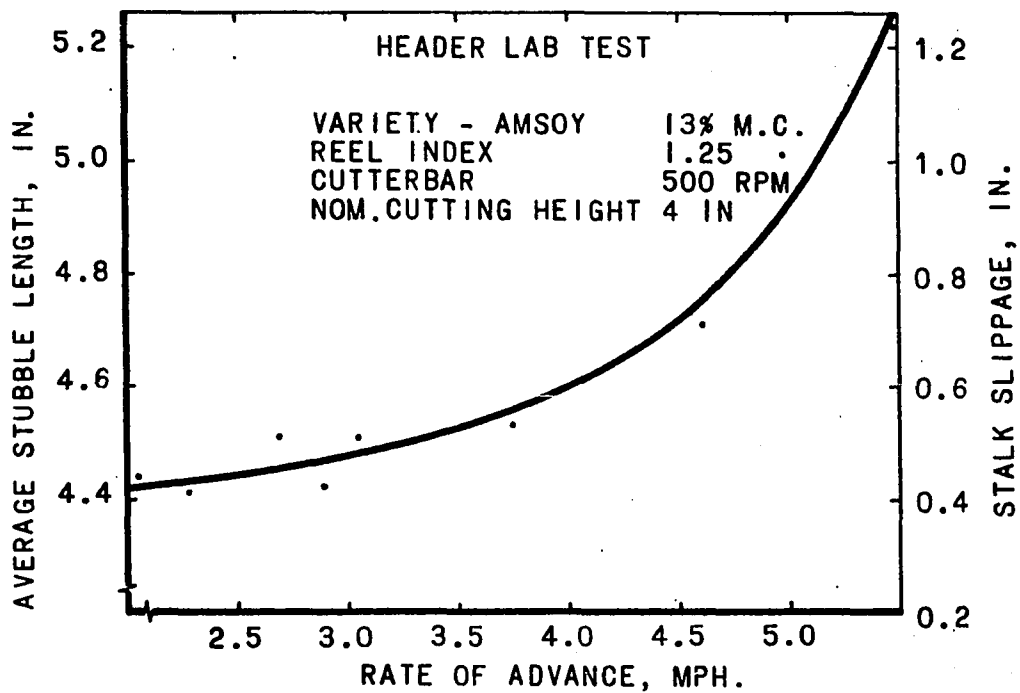


Figure 85. Influence of rate of advance on stubble length.

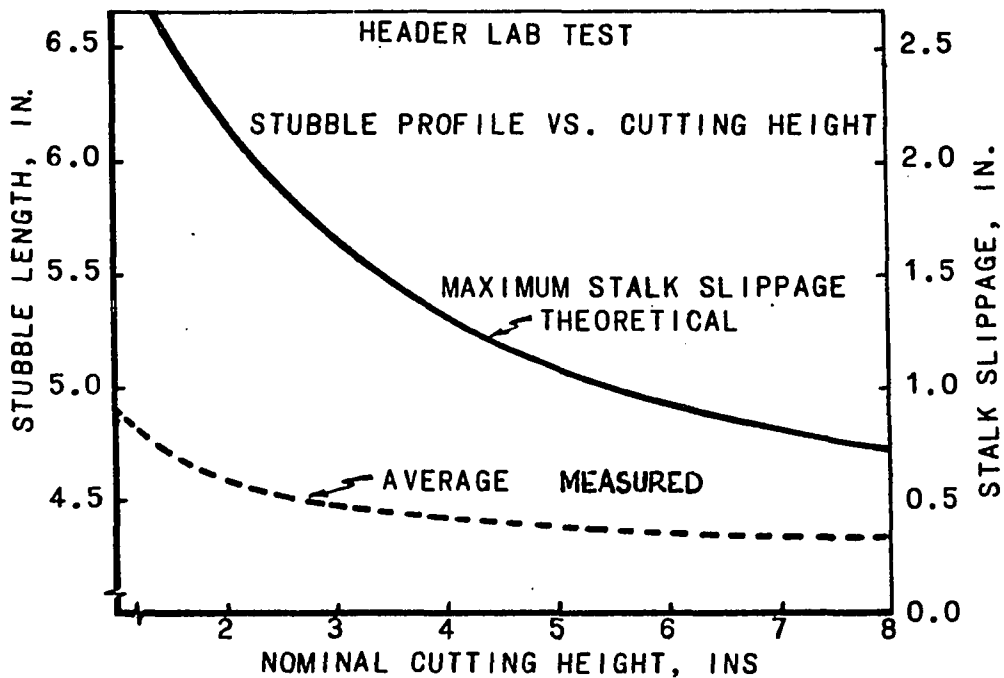


Figure 86. Influence of cutting height on stubble length.

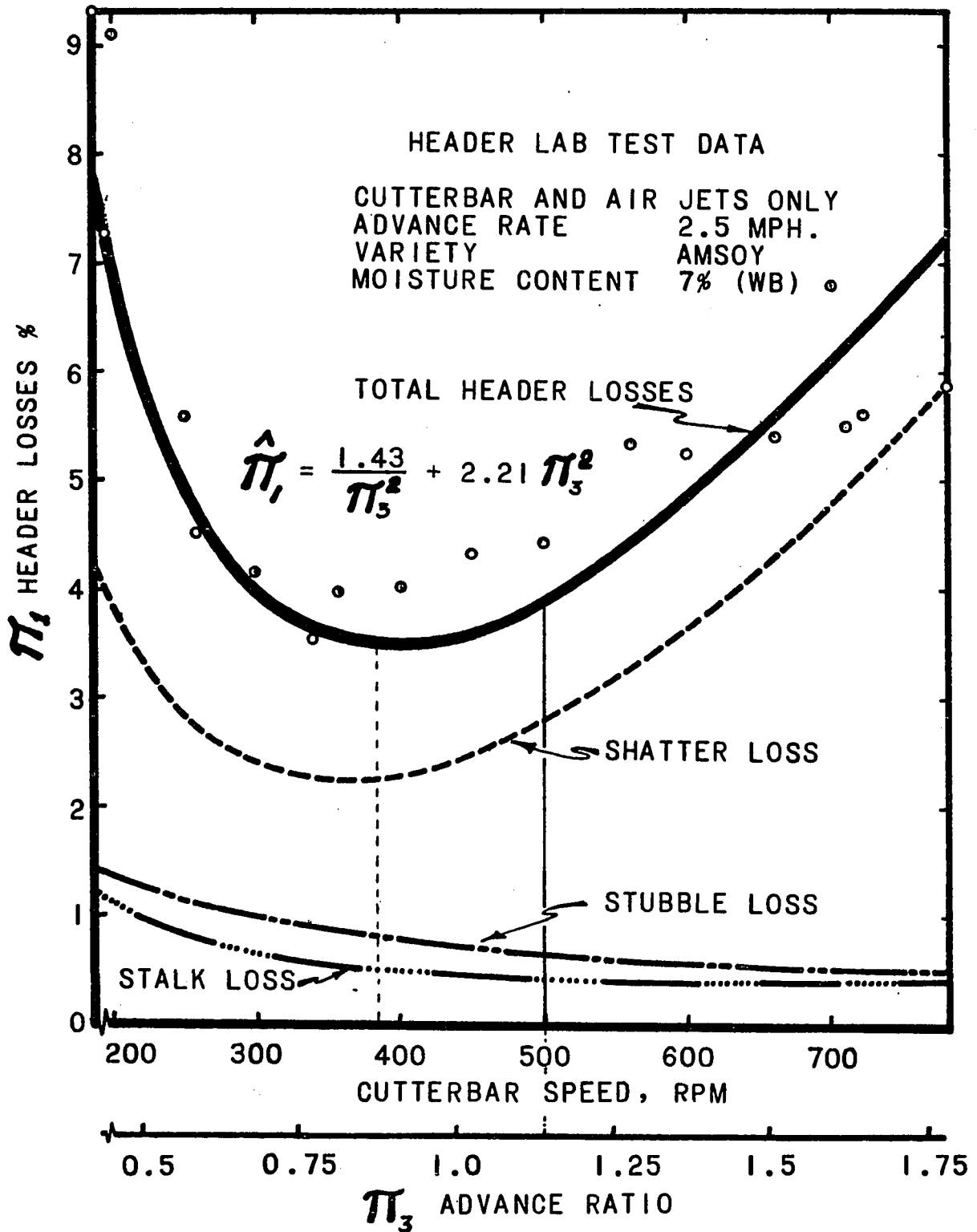


Figure 87. Influence of cutting speed on header losses.

stalks on losses, as discussed in section 6.4. Predicted optimum cutterbar speed in this test was 395 rpm. If the optimum advance ratio of 0.897 is used as an operational criterion, then the upper limit set by header loss for the combine with a cutterbar running at 500 rpm would be 3.17 mph.

The present reciprocating cutterbar design poses a dilemma:

- if operated too fast it lacks durability
- if operated too slowly, or if the combine is driven too fast (for example, over 3.2 mph), header loss becomes excessive.

For increased capacity from a rigid platform header, the following alternative reciprocating higher speed cutterbars might be considered:

- a cutterbar driven from both sides, with counter-balance weights
- a split cutterbar with each half driven separately and with opposing action for balance
- the counter-acting double-knife concept.

The following two sections deal with methods for reducing header loss with the reciprocating cutterbar.

8.8 Influence of Guard Spacing on Header Losses

To test the premise that a narrower guard spacing would promote a shorter stubble length and reduce losses (by reducing stalk displacement and slippage, as predicted from Equation 8-7), the spacing on a special set of combine guards was halved¹, Figures 88 and 89.

¹Built especially for this experiment, from forged steel guards, by Buchanan Steel Products, Buchanan, Michigan, through the courtesy of John Cress, General Manager.



Figure 88. Case 660 combine equipped with a "low cutting" reciprocating knife design. Note movie camera mounted inside divider, left.

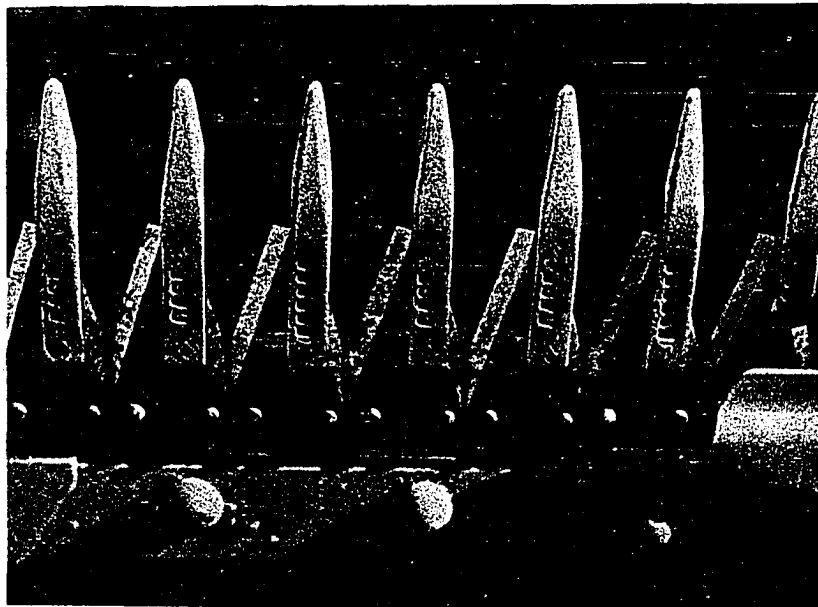


Figure 89. "Low cutting" knife with special 1-1/2 in. guard spacing and 1-1/2 in. sickle sections.

Four guard and knife section combinations were field tested in the 1968 and 1969 seasons, see Tables 30 and 31 (data in A-26 and A-27).

No problems with weeds were encountered with the 1-1/2 in. guards, even though there was only a 1 in. spacing between the guards. This cutterbar was also successfully operated in lodged grain sorghum.

Table 30. 1968 field comparison^a of reciprocating cutterbars. Four cutterbar configurations, cutterbars mounted on 10-ft headers of Case 600, 660 and 900 combines. Machine speeds averaged $3.0 \pm 7\%$ mph; reel index 1.42, nominal cutting height - 4 in. Variety Amsoy, 13.2% average MC, 0.3% pre-harvest loss.

Cutterbar configuration	Average header losses, percent of YLDNP				Bin yield bu/acre	Stubble length in.
	Shatter ^b	Stalk & lodged	Stubble	Total ^c		
Standard						
3 in. guard x 3 in. knife section	4.11	11.13	0.34	15.58	37.99	4.22
3 in. guard x 1-1/2 in. knife	2.60	10.96	0.78	14.34	40.33	4.33
1-1/2 in. guard x 3 in. knife	2.44	8.10	0.44	10.98	41.89	3.83
1-1/2 in. guard x 1-1/2 in. knife	2.40	8.32	0.73	11.45	41.77	3.98
Conclusions (cutterbars, AOCV)	*	n.s.d.	n.s.d.	n.s.d.	n.s.d.	* (AOV)

^aThree-way analysis of covariance, with stubble length as covariate. Treatments: Blocks (3), Cutterbars (4), Locations (3). One direction of travel, two sub-samples per plot.

^bBlock effect was significant (at the 10% level) for shatter loss, as was cutterbar effect. Some patches in the field had considerable lodging.

^cTotal header loss for the 1-1/2 x 1-1/2 in. cutterbar was 26.6% lower than the standard 3 x 3 in. cutterbar, although the difference was not significantly different (at the 10% level). This is a potential saving of 1.53 bu/acre, and primarily arose from the reduction in shatter loss.

Table 31. 1969 field comparison^a between standard 3 in. x 3 in. reciprocating cutterbar on Case 600, and the 1-1/2 in. x 1-1/2 in. special cutterbar on Case 660 at two cutting height settings.^b Variety Corsoy, 11.5% MC. Reel index 1.3.

Cutterbar	Average header losses, percent of YLDNP				Bin yield bu/acre
	Shatter	Stalk & lodged	Stubble	Total ^c	
Standard 3 in.guards x 3 in.knife section	1.81	5.19	4.07	11.08	41.4
1-1/2 in. guard x 1-1/2 in. knife	1.13	4.61	3.27	9.01 ^d	42.3

^aFour-way analysis of variance. Treatments: Blocks (4), Cutterbars (2), Cutting heights (3.5 and 7 in.), Speeds (2.0 and 2.9 mph). Two sub-samples per plot.

^bEffect of heights of cut was highly significant on all loss categories.

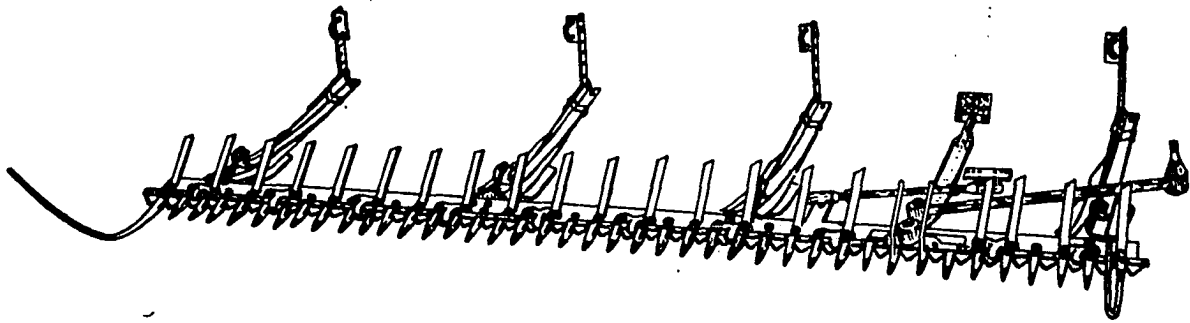
^cEffects of speeds and blocks were not significant (at the 10% level).

^dTotal header loss for the 1-1/2 in. x 1-1/2 in. cutterbar was 18.8 percent lower than the standard cutterbar, a difference significant only at the 10% level.

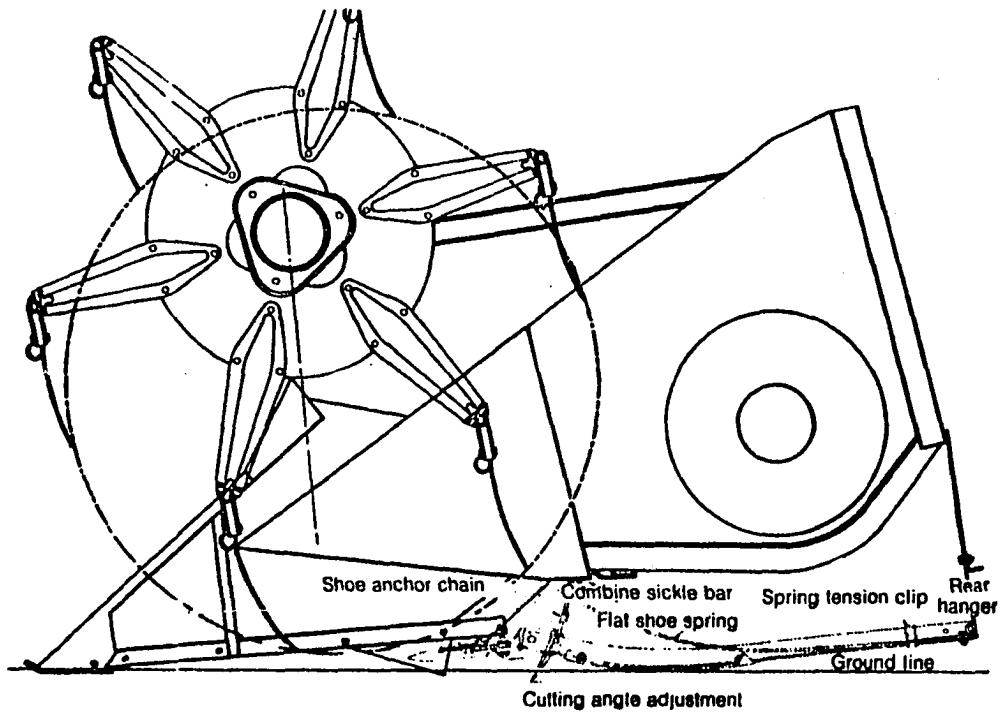
Extremely heavy weed infestations or larger-stemmed weeds of stem diameter approaching 1 in. were not encountered.

8.9 The Floating Cutterbar

The most important advance in header design in decades has been the development of the floating cutterbar. This device, Figure 90, which is not as yet available as original equipment on new combines, is fitted by removing the standard cutterbar and mounting the unit flexibly under and ahead of the platform. The unit is usually spring supported, so that it



A. J. E. Love floating cutterbar.



B. Hart-Carter unit. Note double-hinged floating divider.

Figure 90. Two commercial floating cutterbar header attachments.

floats lightly on skids on the ground surface, Figure 90B.

8.9.1 Floating cutterbar compared with the standard header:

A test was undertaken in 1967 to provide a paired comparison between the J. E. Love Company's 10-ft "Lovebar" mounted on the Case 660 combine and a Case 600 standard fixed platform combine. Both combines were equipped with header height controls.

Table 32. 1967 field test comparison^a between a floating cutterbar and the standard header. Variety Amsoy, 13% MC, combine speed 2.5 mph (data in Table A-28).

Treatment	Average total header loss, percent	Average stubble length, in.
Lovebar, flexible floating cutterbar	8.51	3.22
Standard, fixed platform header	14.14	4.33
Conclusions	**	* (AOV)

^aAnalysis of covariance, with stubble length as covariate, two headers, two directions of travel, four blocks, 10 sub-samples per plot. Blocks x headers interaction was significant. Directions of travel were not significant (at the 10% level).

The loss reduction obtained with a floating cutterbar was substantially dependent upon the degree of difference in cutting height obtained. Note the header loss vs. stubble length plots in Figure 92. Exponential functions were best fitted to the data. In this test the average cutting height difference was 1.11 in. and the overall difference in header loss was 1.75 bu, a highly significant reduction of 39.8 percent. Harvested

yield was 8.21 percent higher with the Lovebar.

8.9.2 Advantages of the floating cutterbar:

1. Substantial reduction in header loss, due to increased pickup of crop, which leads to higher net yields.
2. The cutterbar, being flexible, readily accommodated to ground irregularities, and to tilting of the header (as portrayed in Figure 63). Some cross-wise flexing of the bar was also possible.
3. Crop lifters were not needed with a floating cutterbar (some farmers on the West Coast use the floating cutterbar as a swath-pickup device).
4. A combine cutterbar bears the brunt of any adverse field conditions. Should an obstruction be encountered by the lighter floating cutterbar, the operator has some time to react as the floating assembly can absorb some of the shock, before the more expensive and heavy platform assembly is damaged.
5. The slope between the cutterbar and platform provided a space for the plants to be deposited for better feeding under the auger (usually the cutterbar is extended ahead at least 18 in.).
6. Rocks were less likely to be conveyed up the apron by the reel, and thus the auger and the remainder of the machine were further protected from damage.

8.9.3 Air conveyor and floating cutterbar:

In 1967, Quick developed an air conveying platform for a single row plot combine header, Figure 94, and the general principle was demonstrated as a satisfactory means for conveying soybeans (60). On this machine, the crop was fed directly to the cylinder throat. No full scale combine air

conveyor was built, but the principle was found suitable for fruit conveying on a strawberry harvesting machine. In 1969 Nave et al. (49) successfully used the principle on a 13-ft wide extended platform and fixed cutterbar header. It remained for Tate (75) to take the next logical step and install an air conveyor behind a floating cutterbar in 1970, Figure 91. The first season's trials on this unit were successful and are summarized in Figure 93. Tate concluded that the slight improvement in harvesting efficiency would not justify the extra expense of the air conveying system at this stage of development. Both the floating cutterbar headers showed a highly significant reduction in header loss, by comparison with the standard John Deere floating platform header. An analysis of covariance was not performed, and it is possible that the differences may have been merely attributable to the ability to cut lower with the floating cutterbars.

8.10 Impact Cutting - Field Testing the "Machete" Cutterbar

In the quest for increased header capacity, without increased losses, replacements were sought for the standard cutterbar on the rigid platform. If an improved cutterbar could be found, it would be reasonable to then proceed to design a "floating" version.

Some of the alternative cutterbars considered are tabulated in Table A-29, and their relative merits considered by allocating to each design a figure of merit: a number whose magnitude is an index to the merit or desirability of the alternatives (44). The most meritorious design listed was the continuous belt cutterbar.

Locati, of the Saw Chain Division, Omark Industries, Portland,

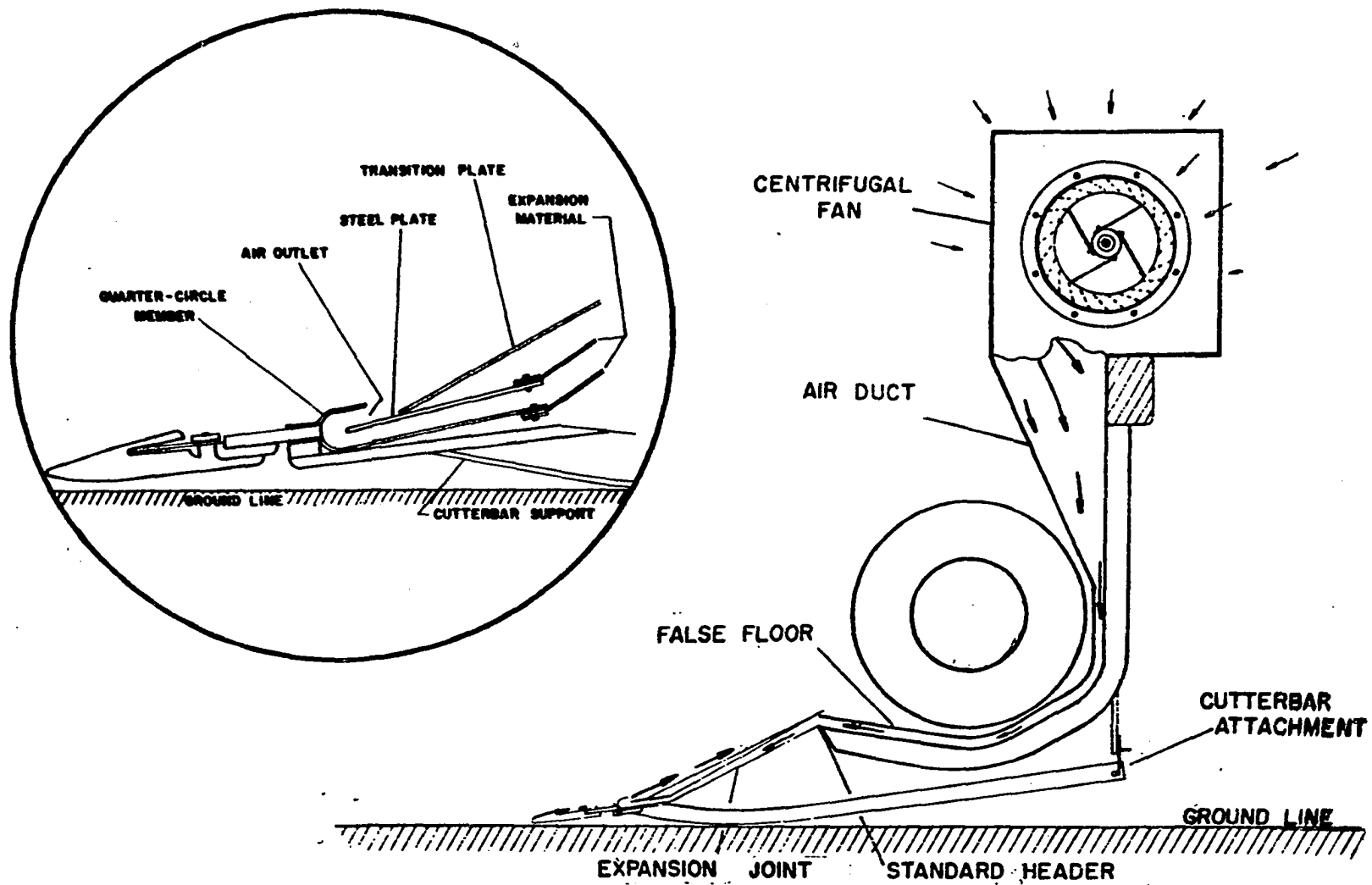


Figure 91. Illinois air conveyor-floating cutterbar attachment for soybeans (75).

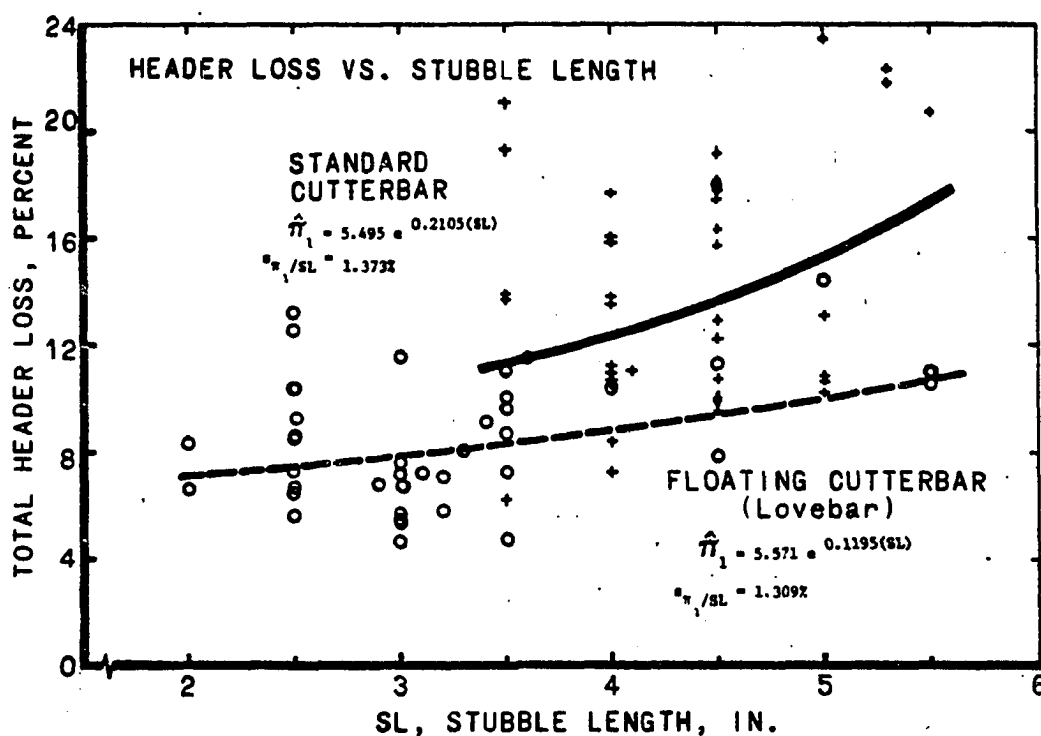


Figure 92. Influence of stubble length on total header loss. Data from field comparison between Lovebar and standard header.

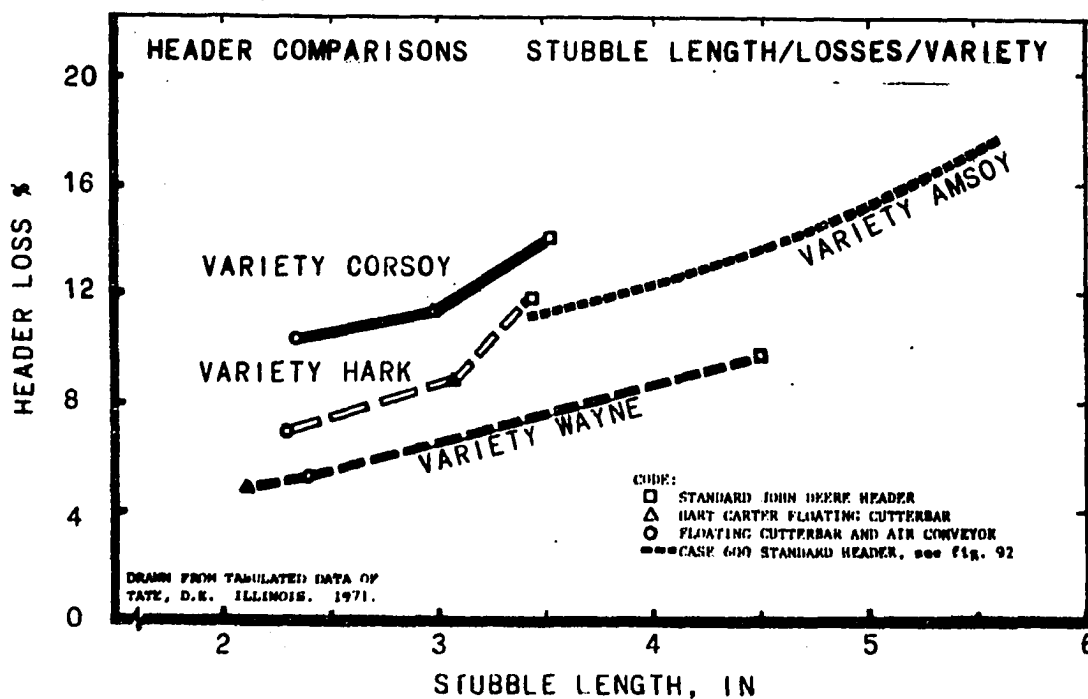


Figure 93. Tate's header comparison data (75).

Oregon, designed, patented (39) and built a continuous belt cutterbar for the high speed mowing of grass and legumes, Figure 95. Considerable developmental work at Omark Industries has gone into the means of attaching the blades to the belt, and details of the belt attachments are proprietary information. Permission was granted to test a prototype seven ft model in the first known application of a belt cutterbar to a combine. The cutting unit was named "the Machete" and work began late in 1970 on installing it on the Case 960 header.

The standard cutterbar was removed and the Machete cutterbar mounted on the right half of the 13-ft header. The other half was fitted with the 10 in. extended platform and standard reciprocating cutterbar, so that both units were approximately the same distance ahead of the auger centerline and at the same mean height above the ground. A rod-divider was mounted at the join between the two cutterbars, Figure 96.

The maximum power requirement of the Machete was stated as three hp at belt speeds around 7,500 fpm. This blade speed was the upper limit set by belt durability considerations. The cutterbar was designed to be driven from the threshing cylinder variable speed belt drive, Figure 97. The cutting blades were raked at 45° and traveled away from the center of the header, towards the right hand divider. The header was equipped with a Noble Electro-hydraulic header height control. First "shakedown" trials were run (April 1971) in over-wintered soybeans. The device performed well and demonstrated the ability to cut at ground level or through ridges, without plugging. There was no tendency to draw the header into the ground, as occurred with the reciprocating cutterbar under the same

Jan. 19, 1971

G. R. QUICK

3,555,790

AERODYNAMIC GRAIN HANDLING SYSTEM

Filed Aug. 3, 1969

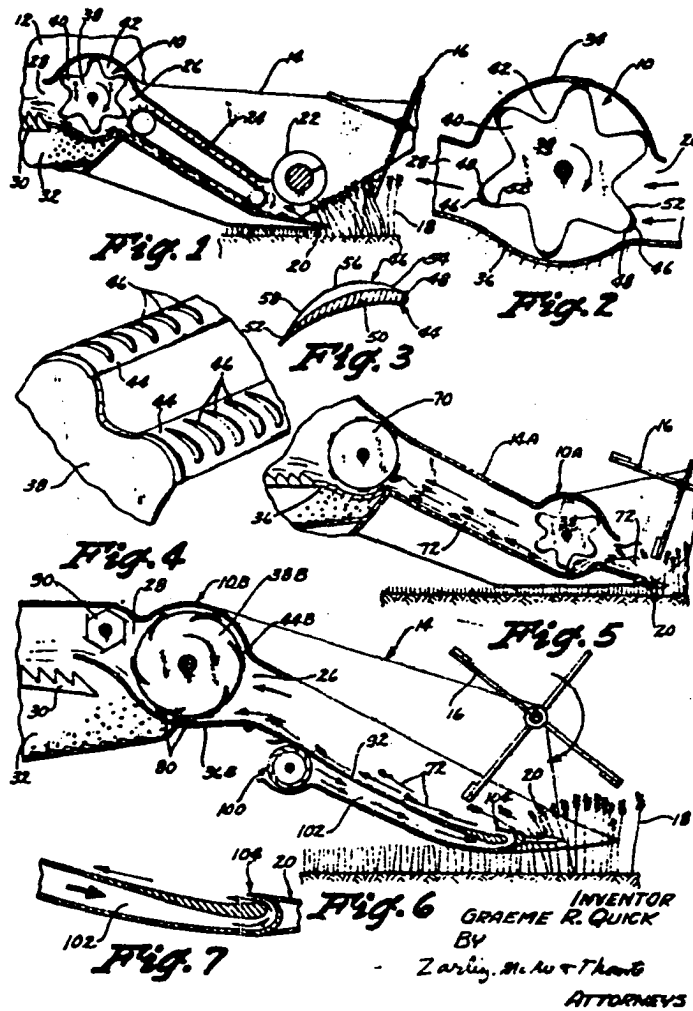


Figure 94. Aerodynamic grain handling system (60).

Dec. 8, 1970

N. C. LOCATI

3,545,188

IMPACT MOWING APPARATUS AND SYSTEM

Filed Sept. 18, 1969

5 Sheets-Sheet 1

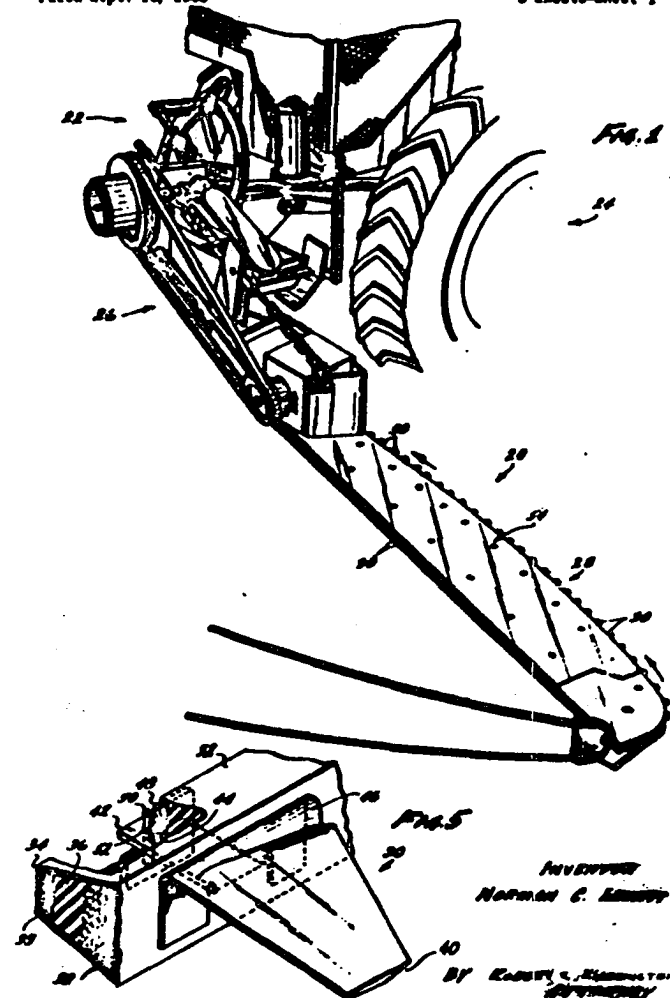


Figure 95. Impact mowing apparatus (39).

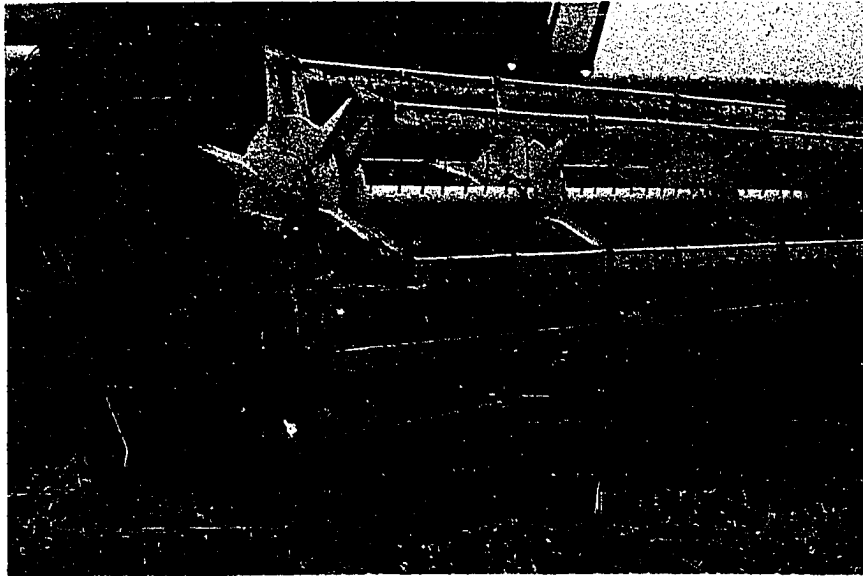


Figure 96. Case 960 combine equipped with the "Machete" continuous belt cutterbar on the right hand half of the 13-ft header.

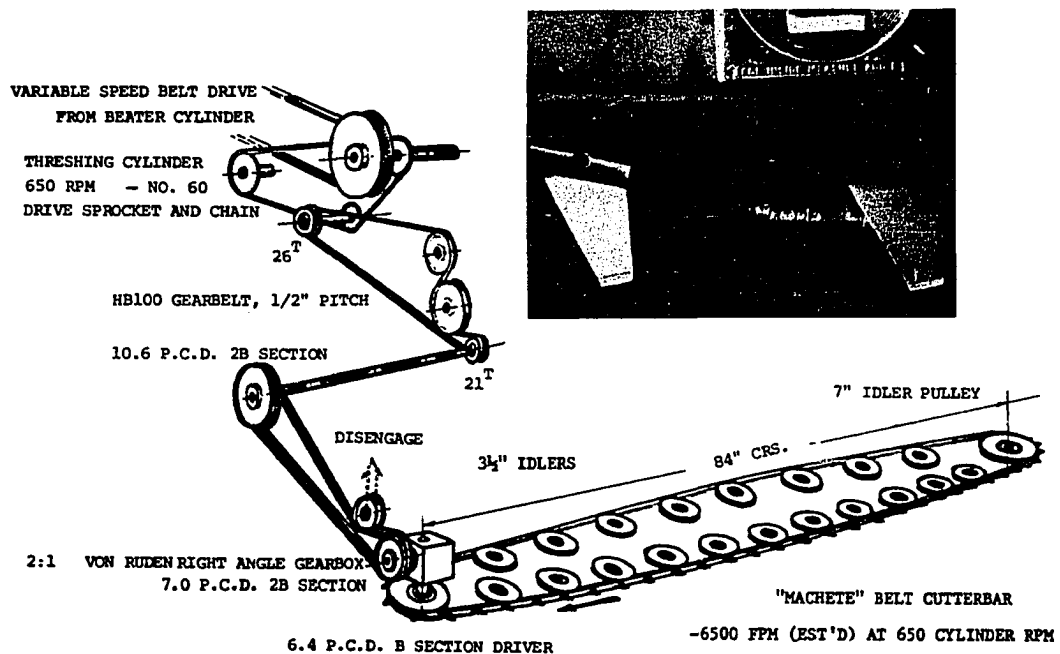


Figure 97. Schematic layout of drive from cylinder for the Machete. Inset shows two of the impact cutting blades.

soft ground conditions if cutting too low. Where the soybean plants were sparse, individual plants would frequently be hurled against the outer row divider. Shattered beans provided confirmatory field evidence of the shattering propensity of single impact cutting. The unit was also operated in corn stubble at high forward speeds and again demonstrated the ability to cut low and pickup plant stalks, while cutting cleanly without benefit of the reel. Thus encouraged, several minor modifications were made to prepare the unit for the soybean season later in 1971.

The lodging encountered in the 1971 season (30% of the stems below horizontal) and soft ground, provided an opportunity to test the combine under conditions unfavorable to both cutterbars.

In order to account for the fact that soybean yields from the two cutterbars were received and measured in a common grain tank, the following correction formula was used for modifying the computations in the program seen in Figure 33:

Assume net potential yield in the two rows harvested by each cutterbar was the same. (The row between the two cutterbars was pulled out and removed before the tests). Bin yield from one cutterbar = net potential yield minus losses from that cutterbar. (8-12)

$$\text{i.e. BINYE (1) = YLDNP - TOHL (1) (lb./acre units)} \quad (8-13)$$

$$\text{BINYE (2) = YLDNP - TOHL (2) (lb./acre units)} \quad (8-14)$$

$$\text{Measured BINYIELD = BINYE (1) + BINYE (2)} \quad (8-15)$$

$$\text{and YLDNP = } \frac{\text{BINYIELD + TOHL (1) + TOHL (2)}}{2} \quad (8-16)$$

These equations can be solved for TOHL (1) and TOHL (2).

Then header loss, percent:

$$\text{THPCT (1)} = \frac{\text{TOHL (1)}}{\text{YLDNP}} \times 100\%, \text{ etc.} \quad (8-17)$$

The header loss computational program was appropriately modified to make these additional calculations. Equality of net potential yield values for both cutterbars in a given run provided a means for checking the validity of the computations, Figure 98.

The results of the full-scale test on the Machete, paired with the standard reciprocating cutterbar, are tabulated in Table 33.

8.10.1 Influence of forward speed on header characteristics: Machete vs. standard cutterbar:

In Figure 99, the results of this test and subsequent field runs at various forward speeds are displayed (data in Table A-31). The prediction equations for the Machete and standard cutterbars for total header loss $\hat{\pi}_1$ vs. forward speed V (fpm) were:

$$\begin{aligned} \text{MACHETE:} \quad \hat{\pi}_1 &= 14.110 e^{0.0006V}, & (8-18) \\ S_{\pi_1/V} &= 1.284\% . \end{aligned}$$

$$\begin{aligned} \text{STANDARD:} \quad \hat{\pi}_1 &= 7.711 e^{0.0031V}, & (8-19) \\ S_{\pi_1/V} &= 1.455\% . \end{aligned}$$

The average stubble length and header loss graphs increased with combine forward speed in a parallel manner for the two cutterbars. Exponential functions were fitted on the data, Figures 99 and 100.

8.10.2 Influence of moisture content on header losses: Machete vs. standard cutterbar:

The results of several tests under different crop moisture conditions are illustrated in Figure 101. The best performance of the Machete in the

```

      14244GROUICK ,TIME=1,PAGES=10
C ***** PROGRAM TO TABULATE HEADER LOSS DATA AS PERCENTAGE OF
C NET POTENTIAL YIELD FOR FIELD TRIALS OF COMBINE HEADERS
C IN SOYBEANS . ***** GRAEME R. QUICK *****
C
C      INDEX = DATA - END INDEXING NUMBER
C      IDENT = PLOT IDENTIFICATION
C      FRASI = SIZE OF MEASURING FRAME , SQ.FT.
C      PREHAR= PRE-HARVEST LOSS , LBS/ACRE
C      TRUCOL= THRU-COMBINE LOSSES , LBS/ACRE
C      PLOTSI= SIZE OF FIELD PLOT , SQ.FT.
C      RINYE = RIN YIELD , ACTUAL PLOT YIELD
C      RINPA = RIN YIELD ,CONV. TO LBS/ACRE
C      SHAPFF= SHATTER (PREHARV)LOSS IN BEANS/FRAME
C      STABPF= STALK ,OR CUTTERBAR,LOSS- BEANS/FRAME
C      XLORPF= LODGED LOSS BEANS/FRAME
C      STURPF= STURBLE LOSS BEANS/FRAME
C      SHALPA , ETC = SHATTER LOSS , ETC , LB/A
C      TSHLPA= TRUE SHATTER LOSS , LB/A ,
C      = SHALPA - PREHAR
C      SHAPCT , ETC = SHATTER LOSS , PERCENT
C      OF NET YIELD , ETC
C
I      DIMENSION STLPA(5) , XLLPA(5) , STUPA(5) , TSHPA(5)
      9, THLPA(5) , RNPA(5) , IDEN(5) , STUBL(5) ,
      8SHPC(5) , STPC(5) , STUPC(5) , XLPCT(5) , THPCT(5)
2      50 READ (5,10) INDEX, FRASI , BEAPP , PREHAR , TRUCOL , PLOTSI
3      10 FORMAT ( I1 , F9.4 , 4F10.4 )
4      IF ( INDEX .GE. 9 ) GO TO 300
5      WRITE (4 , 100) FRASI , BEAPP , PREHAR , TRUCOL , PLOTSI
6      100 FORMAT ( /5X , 'EXPT INPUT DATA',/,5X,5F10.4 )
7      WRITE (4 , 150 )
8      150 FORMAT ( /5X , 'HEADER LOSS DATA EXPRESSED AS PERCENTAGES',
      9//,5X , 'PLOT',3X,'SHATTER',2X,'STALK',3X,'LODGED',2X,
      10'STUMBLE',3X,'TOTAL' , 2X , 'NET POTL', ' STBL'
      119 , /5X , 'IDENT' ,4X , 'LOSS' ,4X , 'LOSS' ,
      1204X , 'LOSS',4X , 'LOSS',3X , 'HOR LOSS' ,2X , ' YIELD HT',/,
      13955X , 'LB/ACRE', ' INS'//)
9      4 I = 0
10     5 READ (5,20,END=300)IDEN , SHAPFF , STABPF , XLORPF
11     8, STURPF , RINYE , STUBL
12     20 FORMAT(I1,X, F6.1 , 3F10.1 , F12.2 , F6.2 )
13     IF( IDEN .EQ. 0 ) GO TO 50
14     SHALPA = SHAPFF * 43560.0 / ( FRASI * BEAPP )
15     STALPA = STABPF * 43560.0 / ( FRASI * BEAPP )
16     XLOLPA = XLORPF * 43560.0 / ( FRASI * BEAPP )
17     STULPA = STURPF * 43560.0 / ( FRASI * BEAPP )
18     TSHLPA = SHALPA - PREHAR
19     IF ( TSHLPA .LT. 0.0 ) TSHLPA = 0.0
20     TOLHLP = TSHLPA + STALPA + XLOLPA + STULPA
21     RINPA = RINYE * 43560.0 / PLOTSI
22     I = I + 1
23     IDEN(I) = IDEN
24     TSHPA(I) = TSHLPA
25     STLPA(I) = STALPA
26     XLLPA(I) = XLOLPA
27     STUPA(I) = STULPA
28     THLPA(I) = TOLHLP
29     STUBL(I) = STUBL
30     IF ( I .EQ. 2 ) GO TO 29
31     GO TO 5
32     29 BNPA(2) = (2.0* RINPA - THLPA(2) + THLPA(1) ) / 2.0
33     BNPA(1) = RNPA(2) + THLPA(2) - THLPA(1)
34     YLONP = BNPA(1) + THLPA(1) + TRUCOL
35     SHPC(1) = TSHPA(1) / YLONP * 100.0
36     STPC(1) = STLPA(1) / YLONP * 100.0
37     XLPCT(1) = XLLPA(1) / YLONP * 100.0
38     STUPC(1) = STUPA(1) / YLONP * 100.0
39     THPCT(1) = THLPA(1) / YLONP * 100.0
40     WRITE ( 6,200 ) IDEN(1),SHPC(1) , STPC(1) , XLPCT(1) ,
41     8STUPC(1) , THPCT(1) , YLONP , STUBL(1)
42     SHPC(2) = TSHPA(2) / YLONP * 100.0
43     STPC(2) = STLPA(2) / YLONP * 100.0
44     XLPCT(2) = XLLPA(2) / YLONP * 100.0
45     STUPC(2) = STUPA(2) / YLONP * 100.0
46     THPCT(2) = THLPA(2) / YLONP * 100.0
47     WRITE ( 6,200 ) IDEN(2),SHPC(2) , STPC(2) , XLPCT(2) ,
48     8STUPC(2) , THPCT(2) , YLONP , STUBL(2)
49     GO TO 4
200 FORMAT (4X,I5, 2X , 4F8.4 , F10.4 , F9.2 , F5.2 )
300 STOP
      END

```

BPNTBY

Figure 98. Modified program to convert field data. Used for paired comparisons where crop from the two header treatments is received in a common grain bin.

Table 33. 1971 comparison^a in a field test between the Machete continuous belt impact cutterbar paired with a standard reciprocating cutterbar on the Case 960 combine. Reel index 1.5 nominal, reel set 4 in. above and 7 in. ahead of cutterbars. Variety Amsoy at 13% MC, with 30% lodging. (Data in Table A-30).

Cutterbar	Speed, mph	Average header losses, percent					Stubble length, in. ^g
		Shatter ^b	Stalk ^c	Lodged ^d	Stubble ^e	Total ^f	
MACHETE	1.6	9.72	5.77	1.40	0.23	17.12	3.85
	2.7	4.44	8.88	1.10	1.04	15.45	4.54
	3.2	9.10	6.95	1.80	0.28	18.13	4.30
Av. over all speeds		9.42	6.50	1.63	0.28	17.83	4.24
STANDARD	1.6	4.17	8.83	1.55	1.17	15.72	5.18
	2.7	9.43	6.78	1.70	0.32	18.24	4.58
	3.2	5.21	8.27	1.26	1.36	17.11	6.05
Av. over all speeds		4.61	8.66	1.63	1.19	16.09	5.25
Conclusions:						Diff. sig.	
(Cutterbars, AOCV)		**	n.s.d.	n.s.d.	**	at 10% level	** (AOV)

^aThree-way analysis of covariance with stubble length as covariate. Treatments: Cutterbars (2), forward speeds (3), blocks (4). Directions of travel were pooled to provide a total of 8 replications, with four sub-samples per plot.

^bShatter loss: the Machete produced a 104% increase in shatter loss over the standard cutterbar, a highly significant difference.

^cStalk loss: with the Machete was 25% lower, but the difference was not significant at the 10% level. This was the largest loss cause.

^dLodged loss: was equal for both cutterbars.

^eStubble loss: was 77% lower with the Machete, a highly significant reduction. (Many pods on the stubble were shattered by the cutting action).

^fTotal header loss: was 4.6% higher with the Machete. This difference was only significant at the 10% level.

^gStubble length was 19.2% lower with the Machete, a highly significant difference, which increased in favor of the Machete as combine forward speed was increased.

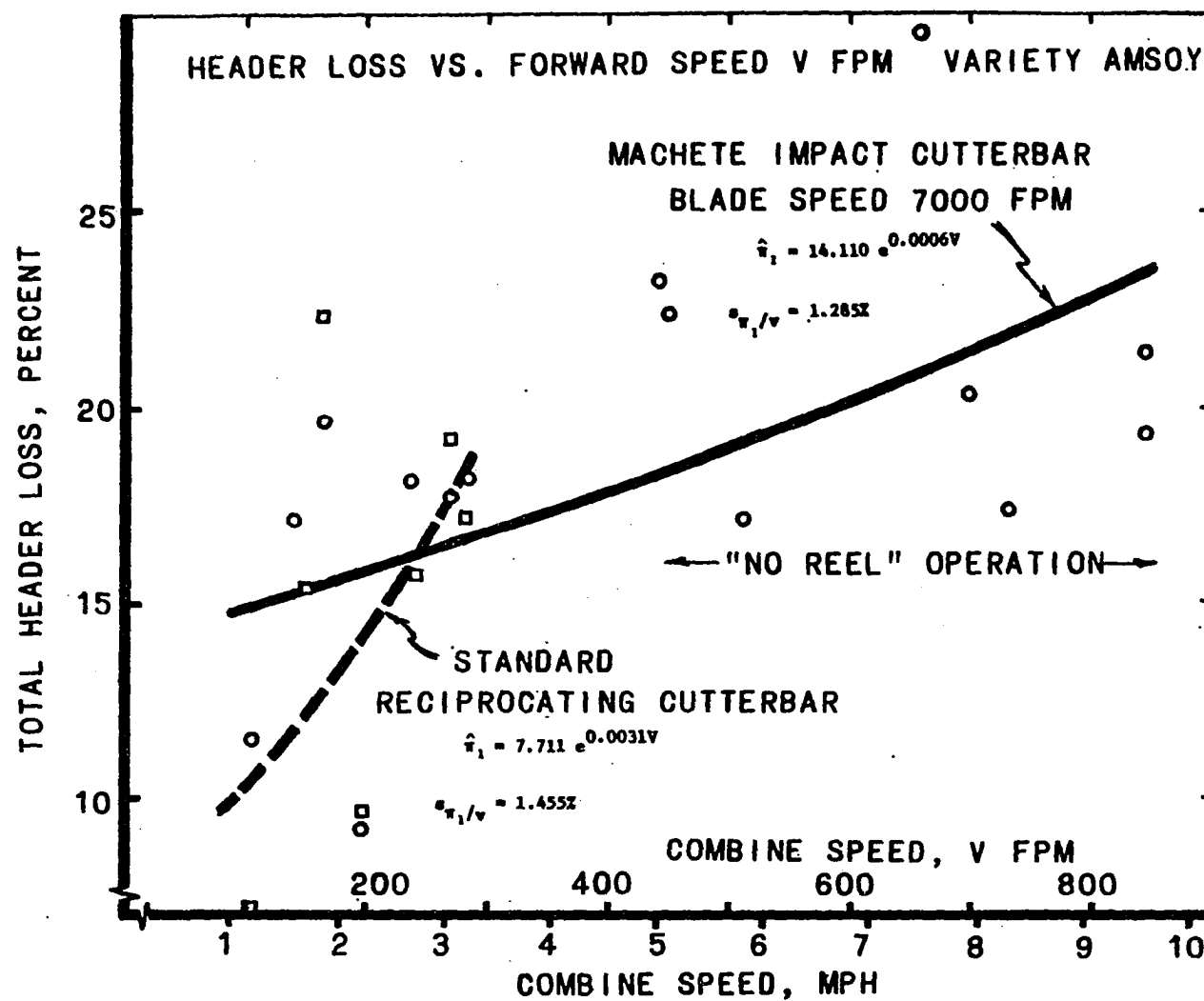


Figure 99. Influence of forward speed on header loss, Machete and standard cutterbars compared.

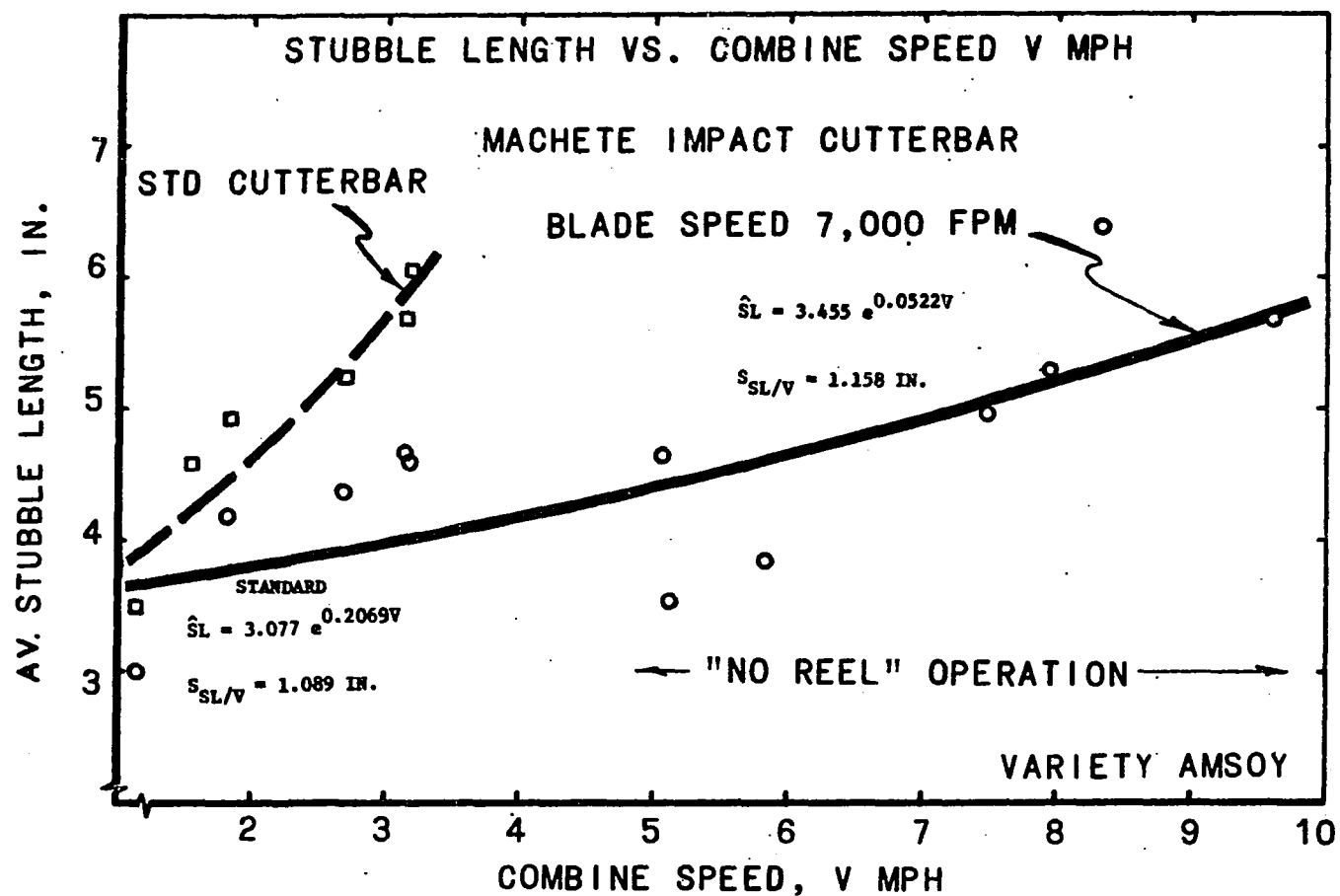


Figure 100. Influence of forward speed on stubble length, Machete and standard cutterbars compared.

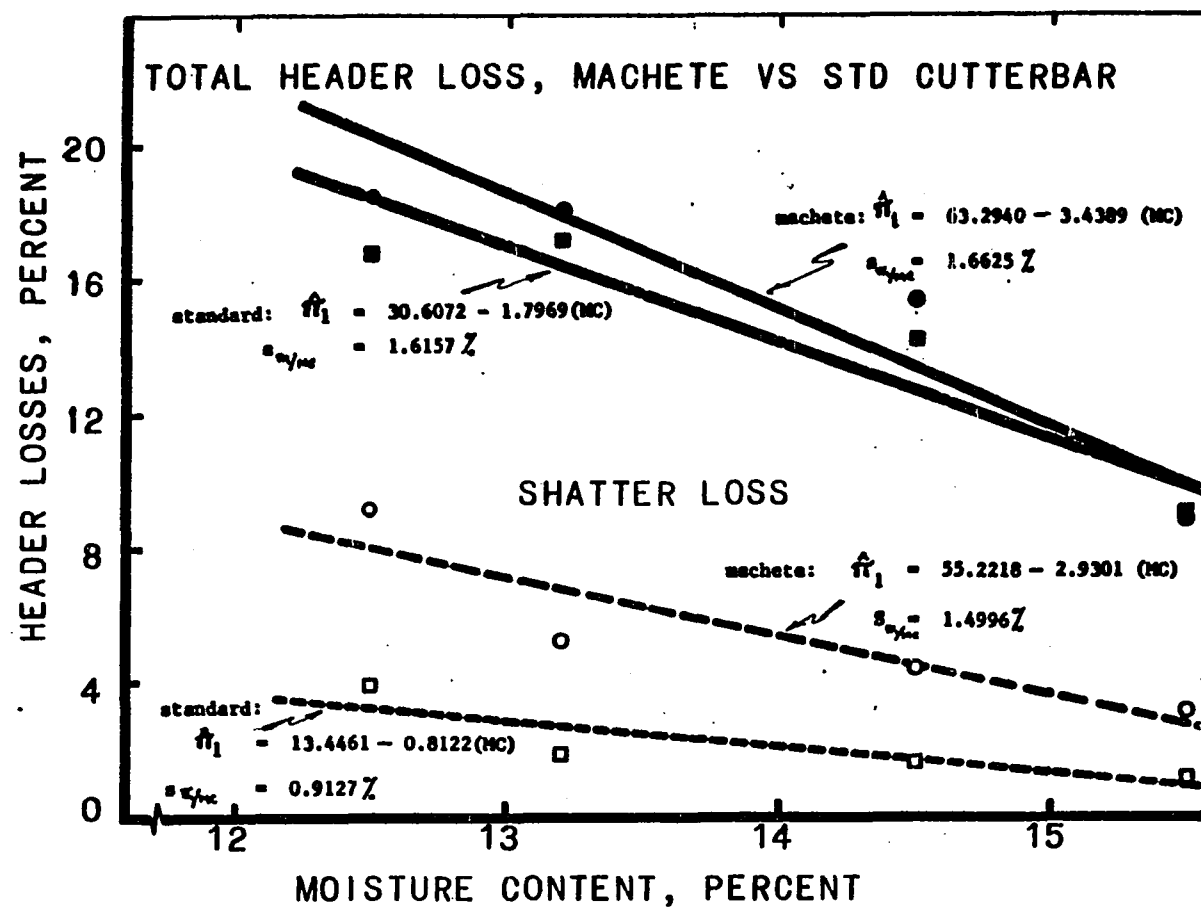


Figure 101. Influence of moisture content on header loss. Machete and standard cutterbars compared at 1.93 mph forward speed, reel index 1.5.

Amsoy beans was 8.73% total header loss at 15.5% seed moisture, 2.5 in. stubble length and 1.09 mph. This was slightly lower than the reciprocating cutterbar, 9.34% header loss. Multiple cutting of most stems was highly probable at this low forward speed.

8.10.3 Multiple impact cutting with the Machete:

Three possible operational conditions are delineated in Figure 102:

- I Stem crowding, Figure 102A. Some stems are bent over by the advancing platform lip before being cut by the blade
- II Zero crowding, single impact cutting; $c = 0$
- III Multiple impact cutting, blade paths overlap.

The blade pitch relationship is (Figure 102A):

$$S = d \tan \alpha + c + \frac{d}{\tan \beta} \quad (8-20)$$

$$= d (\tan \alpha + \cot \beta) + c$$

but $\cot \beta = \pi_3 = \frac{V_b}{V}$ (Advance ratio) (8-21)

$$S = d (\tan \alpha + \pi_3) + c$$

where S = blade pitch, ft

d = blade depth, ft

a = blade width, ft = $d \tan \alpha$

c = crowding distance, ft

t = stem diameter, ft (or in.)

The maximum blade spacing for zero crowding ($c = 0$) is:

$$S_{\max} = d (\tan \alpha + \pi_3) \quad (8-22)$$

For the machete blades and at a combine speed of 375 fpm (4.26 mph), setting $V_{b \max} = 7,500$ fpm, $\pi_3 = 20 : 1$

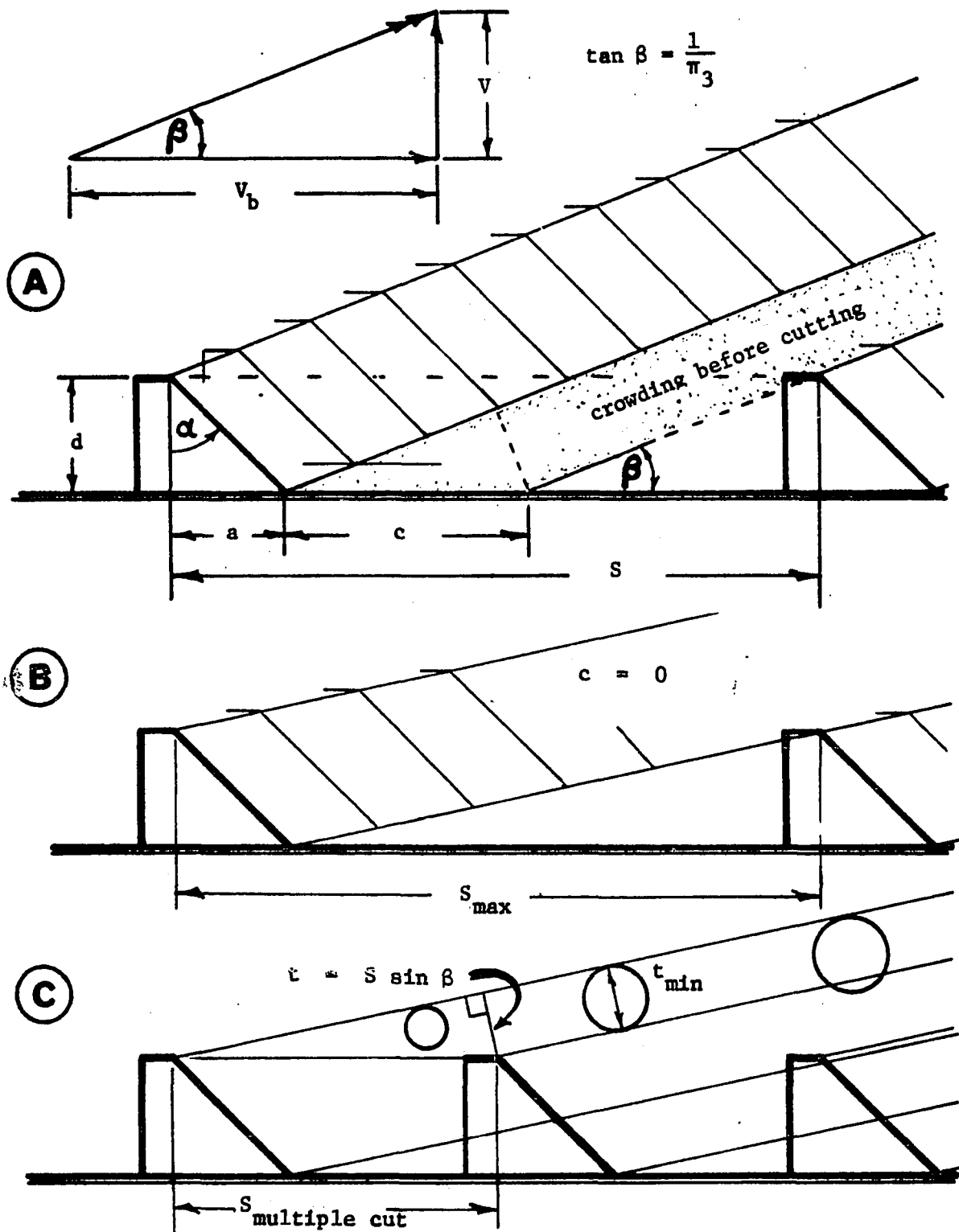


Figure 102. Cutting parameters for the Machete continuous belt impact cutterbar.

$$b = 0.0625 \text{ ft}, \alpha = 45^\circ,$$

$$S_{\max} = 1.3125 \text{ ft (15.75 in.)}$$

i.e. 15.75 in. is the maximum blade pitch for zero crowding and single impact cutting of stems at 4.26 mph forward speed.

The 1971 Machete cutterbar blade pitch was three in. With this blade pitch, the minimum stem size for multiple cutting could be estimated from the relation (see Figure 102C):

$$t_{\min} = S \sin \beta, \text{ and, using a trig. identity,} \quad (8-23)$$

$$t_{\min} = S \tan \beta \frac{1}{\sqrt{1 + \tan^2 \beta}} \quad (8-24)$$

For the previous conditions, and with $S = 0.25 \text{ ft (3 in.)}$, $\tan \beta = 1/20$:

i.e.

$$t_{\min} = 0.15 \text{ in.}$$

Any stem larger than 0.15 in. diameter will be impacted by more than one blade at the 4.26 mph forward speed.

8.10.4 High speed combine operation with the Machete:

The top speed at which the reciprocating cutterbar could be continuously operated in the 1971 field trials was below three mph. Attempts to cut low (2 to 4 in.) resulted in this cutterbar frequently digging into the ground or plugging.

Higher operating speeds were only made possible by raising the cutterbar to a height where lodged loss became extremely large. Even at three mph, stubble length and losses were often unacceptably high. The Machete cutterbar, on the other hand, never plugged, even when the combine was

operated at speeds up to 9.6 mph. At speeds above four mph it was impracticable to speed up the reel to the level necessary to keep reel index constant at the 1.5 value of the other tests. The reel was therefore raised to its upper limit for the high speed runs, where the tines only barely touched the crop. Thus, operation at speeds above four mph was essentially "no-reel" combining, Figure 99.

8.10.5 Summary: the Machete cutterbar for higher header capacity:

The price to be paid for increased header capacity was a much higher shatter loss with the Machete. All other header losses were lower. Stubble length was reduced by a highly significant amount below the standard cutterbar. No plugging was encountered with the Machete even up to 9.6 mph, although field operation at the highest combine speeds was detrimental to the machine and uncomfortable for the operator. Only two rows were harvested (by the Machete) at these speeds, thus, the problem of overloading of the cylinder and cleaning systems was not encountered. It was estimated that a full width Machete-equipped header would have capacity in excess of the throughput capabilities of the remainder of the combine in soybeans.

9. SUMMARY

A substantial improvement in combine harvesting efficiency would make only a modest improvement in the U.S. National Soybean yield. But a header design that substantially reduces gathering loss would make a large difference in the farmers' profit picture. Each percentage point of header loss cost the (Iowa) farmer about one dollar per acre in 1970. Total header loss represented more than 36 percent of his potential profit.

In view of the growing importance of the soybean in this hungry world, work on the most inefficient component of the combine is justified.

Soybeans produce more protein per acre than any other crop. Soybean consumption has exceeded U.S. production for the past several years. To meet the growing demand, acreage will have to be increased at a faster rate than at present. Varietal improvements and better crop management will need to be geared to improvements in harvesting efficiency and header capacity.

With the standard header design, operational speed for least header loss was less than two mph. Increasing capacity by higher speed operation resulted in reduced yield and increased header loss. Since increasing header width and an irregular ground surface make the task of maintaining a uniformly low stubble increasingly difficult with the fixed platform design, the floating cutterbar was considered a highly desirable attachment because of its effect on lowering stubble length. Excessive stubble length was a clear sign of high header loss.

To assess header performance, a standardized field testing technique

and a pertinent glossary of terms were proposed and utilized. An indoor header testing facility and related lab equipment was constructed and used to produce a major portion of the data presented in this thesis. The header lab facilitated testing, extended the harvesting "season," and made possible a wider spectrum of header tests than could possibly have been obtained in the field. Despite certain weaknesses in the lab test facility, especially in the lack of crop storage and conditioning, there was generally a good agreement between the field and lab characteristic curves. A high degree of control over the machine variables was achieved, and over 1,000 runs were made in the lab. The costs of data collection were halved using the lab facility. The use of high-speed photo-instrumentation was facilitated, and by this means, information was obtained and analyses of complex plant-machine interactions achieved in ways unmatched by other instrumentation.

The header lab facility was to prove as important in combine header research as a wind tunnel to an aerodynamicist.

The cutterbar was isolated by individual header component analyses as the primary cause of header loss and lack of capacity. Attention was accordingly given to modification and re-design of this component.

The decision was made, after studying and testing production factors for high yields, that narrow row spacing was mandatory in the Northern soybean regions. Row-crop attachments, however efficacious, are only a stop-gap measure. The Lynch attachment, for example, consistently reduced header loss, but a different attachment is needed for each row spacing. The future lies in open-front header modifications and in floating cutter-bars in particular.

In Table 34, the results from the 1967 to 1971 field trials are summarized. Header loss averaged 10.61 percent of net potential yield (84 percent of all combine losses) overall for the field comparisons in this work. These results were somewhat higher than the 8.93 percent average header loss reported in the literature on soybean harvesting between the years 1927 to 1970, due to lodging in 1971.

The Machete high-speed belt cutterbar demonstrated that higher header capacities were attainable by modifying the cutterbar design. Stubble length was consistently lower and shatter loss higher with the Machete than with the standard cutterbar. Harvesting speeds up to 9.6 mph (without the reel) were attained with the Machete. The clue to reducing the deleterious effects of impact cutting on shatter loss was found in the discovery that multiple high-speed cuts could sever stems without shattering pods.

The Machete cutterbar could be used to advantage in a variety of crops. A floating version would be capable of "topping" soil ridges and mounds without plugging and would enable the operator to cut below the lowest pods in a soybean crop.

Table 34. Summary of treatment and experiment header loss means for 1967 to 1971 field trials detailed in thesis.

FIELD TEST DESCRIPTION	TOTAL HEADER LOSS MEANS, % INDIVIDUAL RESULTS GRAND AVERAGE			COMMENTS
1967 FLOATING CUTTERBAR COMPARISON WITH LOVE- BAR - Amsoy 12.75% MC	STANDARD 14.14 LOVEBAR 8.51	11.32		Header loss reduction of 39.8% using Lovebar, at a 25.7% lower stubble length.
1968 FOUR RECIPROCATING CUTTERBARS COMPARED Amsoy 13.2% MC	STANDARD 15.58 1-1/2x1-1/2 11.45	(4) 13.09		Header loss reduced 26.6% using 1-1/2x1-1/2 cutterbar.
1969 TWO RECIPROCATING CUTTERBARS COMPARED Corsoy 11.5% MC	STANDARD 11.08 1-1/2x1-1/2 9.01	10.04		Header loss reduced 18.8% using 1-1/2x1-1/2 cutterbar.
1969 HEADER CHARACTERISTICS Amsoy 12.5% MC	LOWEST 2.37 HIGHEST 16.83	8.01		Lowest header loss at 1.0 mph., 3 in. cutting height.
1969 WEEDS TRIAL Amsoy 16.0 & 13.5% MC	LOWEST 1.84	5.75		Weeds lowered yield by 22.2% and header loss by 62.9% in this trial.
1969 CULTIVATION TRIAL Amsoy 11.5% MC	HILLED 9.99 FLAT 8.57	9.28		Flat land lowered yield by 15.0% and header loss by 14.2% compared with standard
1970 LYNCH ATTACHMENT COMPARISONS in three varieties at 19.3% MC	STANDARD 5.68 LYNCH 4.33	5.01		Header loss reduced 23.9% by using Lynch attachment.
1970 LYNCH ATTACHMENT COMPARISON at 3 real indices Amsoy 19.3% MC	STANDARD 11.04 LYNCH 6.74	8.89		Header loss reduced 38.9% by using Lynch attachment.
1970 ROW SPACING TRIAL Hark 15.2% MC	30 IN. ROWS 5.94 10 IN. ROWS 4.59	(3) 5.47		Header loss reduced 22.7% by 10 in. rows and yield in- creased 19.9%.
SUMMARY, GRAND AVERAGE HEADER	LOSS, 1967 to 1970:	8.54		Fair to excellent crop con- ditions.
1971 LYNCH ATTACHMENT COMPARISON at 2 real indices - 30% lodged Amsoy, 11% MC	STANDARD 21.10 LYNCH 9.82	15.45		Header loss reduced 53.5% by using Lynch attachment.
1971 EXTENDED PLATFORM COMPARISON 30% lodged Amsoy, 12.3% MC	STANDARD 21.43 EXTENDED (10 IN.) 14.70	18.06		Header loss reduced 31.3%, primarily due to 15.1% re- duction in stubble length.
1971 MACHETE CUTTERBAR COMPARISON 30% lodged Amsoy, 13% MC	STANDARD 16.09 EXTENDED (10 IN.) 17.83	16.96		Header loss increased 4.6% by using Machete cutterbar.
SUMMARY, GRAND AVERAGE HEADER	LOSS, 1967 to 1971:	10.61		Loss adversely influenced by lodging in 1971.

10. CONCLUSIONS

As a result of the field and lab studies the following conclusions were drawn:

10.1 For the Standard Header Design

- (a) Overall header loss in this study averaged 10.61 percent of net potential yield, or 84 percent of all combine losses. The other combine losses were normally very low in soybeans, usually because the remainder of the combine was not loaded to full capacity in this crop.
- (b) The header was the capacity-limiting component of the combine and, for lowest losses, the combine had to be operated between 1.5 to 2 mph. At these speeds and, under ideal conditions, field header loss levels as low as 1.84 percent were obtained. Lowest header losses were recorded in high moisture and weedy field conditions. If the machine was improperly operated in a lodged crop, over 30 percent of the seed could be left in the field. Operation at high forward speeds increased capacity at the expense of reduced yield, higher stubble and increased header loss.
- (c) Header loss appeared to increase exponentially with stubble length and with speed.
- (d) Extended row dividers and crop lifters for lodged beans facilitated field operation of the header.
- (e) The pickup reel was necessary to retrieve stalks in lodged and tangled conditions. The header could not be operated at low speeds without a reel. Optimal reel position and speed was governed by crop

- conditions and cutterbar interactions. The criterion of zero horizontal velocity at entry of reel bar was not suitable in soybeans.
- (f) Ideal reel index range in an erect crop was found to be 1.5 to 1.9, higher than the 1.25 currently recommended by manufacturers.
- "Overspeeding" the reel had less adverse influence on header loss than underspeeding. Reel settings for a lodged crop were completely different from those for an erect crop of soybeans.
- (g) Varying auger speed did not affect header loss in the lab, but evidence was cited to show that, in the field, losses increased due to platform overloading if the auger was underspeeded.
- (h) Correct operation and improved design of the header exerted an influence on the operation of the rest of the combine.
- (i) Ideal cutterbar advance ratio was found in the lab to be 0.9 at 2.5 mph for the standard cutterbar. This suggested that, for a cutterbar operating at 500 rpm, the upper limit on forward speed to avoid overcrowding the knife would be 3.2 mph. In the field this speed may be even lower, depending on ground and crop conditions.
- (j) Highest header loss category was stalk loss. The stalk loss contribution increased with increased stalk lodging and branching. In the lab studies, and under certain field conditions, shatter loss predominated.
- (k) The literature review showed that header loss was the largest single combine loss in many other crops.

10.2 Management and Cultural Practices Affecting Header Loss

- (a) Narrow Row Spacing was the key management factor in raising productivity. Yield on the 10 in. row spacing was 20 percent higher, and header loss was 22 percent lower at 3 mph than in the 30 in. spaced rows in variety Hark at 15.2 percent MC in 1970.
- (b) A controlled weed infestation depressed yield but also reduced header loss.
- (c) Both these management factors affected podding height and degree of branching of the crop, and thereby exerted an important effect on header loss.
- (d) Flat land cultivation for weed control, while not markedly lowering header loss compared with hilling, did make it easier for the operator to harvest lodged plants and reduced the adverse effect of header tilting due to one of the combine wheels riding on the ridge.
- (e) Harvest efficiency was highest if harvesting started as early in the season as the bean moisture fell below 14 percent. Lowest combining losses were recorded during those parts of the day and season when moisture content was near this ceiling. This took advantage of the depressing effect on header loss of increased moisture content. Losses increased approximately exponentially as the crop dried out.
- (f) The agronomic shattering index was inadequate to describe the machine shatterability of a variety. Pod compression testing was the more facile quantitative method of assessing shatterability in the lab. Several aspects of machine shatter were found to correspond with the results of this testing procedure.

10.3 The Cutterbar Was the Prime Cause of Header Loss

It was incriminated by the following evidences:

- (a) By a simple process of elimination in the lab, the cutterbar contribution to header loss was assessed at about 80 percent of total header loss.
- (b) The recurring theme from most of the machine trials conducted was: cut low for minimum header loss. The cutterbar exerted the major influence on stubble length. Most of the header attachments were effective only as they assisted in reducing stubble length and thereby reduced the deleterious effects on header loss of the cutterbar.
- (c) Excess stubble length, due to stalk slippage, was the primary limitation on combine operating speed and header capacity.
- (d) The minimum stubble length attainable was governed by platform depth. Stubble lengths less than three inches were unattainable at normal field speeds with the fixed platform design. Extending the platform forward by 10 in. did not significantly reduce losses (at the 10 percent level).
- (e) Modifications to the reciprocating cutterbar on a fixed platform, such as narrow guard spacing, reduced header loss by as much as 26.6 percent.
- (f) An automatic header height control on a fixed platform header aided the operator in maintaining a lower stubble length.
- (g) The Machete continuous cutterbar substantially reduced stubble length by reducing stalk slippage, even with the fixed platform.

10.4 The Floating Cutterbar Attachment

The floating cutterbar attachment was deemed essential for consistently lower header loss:

- (a) The floating cutterbar, where used with an automatic header height control, ensured lowest possible cutting height across the full width of the header, with least attention from the operator.
- (b) The floating cutterbar provided better crop feeding onto the platform, and reduced the risk of header damage, plugging and plowing under rough field conditions. (The savings in yield would usually pay for the attachment in an average season's operation).
- (c) The air conveying system behind the cutterbar was demonstrated by others to be a further improvement to the floating cutterbar.
- (d) The Lynch row-crop vertical-drum reel attachment substantially reduced header loss (by almost one half). This was primarily due to its effect on reducing stalk loss by controlling plants as they were being cut and the use of lifters with this reel. As now designed, this attachment could not be used with a floating cutterbar or in rows narrower than 30 in.

10.5 The Cutting Action

The cutting action of the standard cutterbar was studied in the field and closely observed by high-speed photo-instrumentation using the lab cutting analyzer:

- (a) The cutting action was found to thrust plants away from the platform. This tendency increased if the cutterbar was crowded, as by operating at an advance ratio of less than 0.9.

- (b) In spite of the effect of cutterbar slippage on pod stripping and cutting, the actual cutting impulses on the stem did not appear to be responsible for shatter.
- (c) Normally, pods could withstand quite a high acceleration environment (up to several hundred g's) without shattering, if not directly impacted.
- (d) Entangled plants and partially dehisced pods would certainly account for more shatter by the header components than would indirect impacts on the stem.
- (e) Continuous cutterbar devices offered the greatest potential for increasing header capacity.

10.6 The High-Speed Continuous Belt Cutterbar

- (a) The Machete cutterbar was capable of field operation without plugging at speeds up to 9.6 mph.
- (b) A highly significant reduction in stubble length was obtained with the Machete, even on a rigid platform.
- (c) Stubble length increased gradually with speed. The reel could be discarded without detriment to header performance at speeds above four mph.
- (d) Shatter losses due to single impact cutting were severe. The higher shatter loss with the Machete offset the reduced stubble and stalk losses, with the result that the Machete produced somewhat higher total header loss under most conditions.
- (e) The high shatter loss due to impact cutting could be diminished if individual stems could be cut in several bites, i.e. by more than

one high-speed blade cutting part way through the stem at each impact. This was accomplished at low forward speeds with the Machete.

The results with the Machete cutterbar were sufficiently encouraging to justify construction of a floating Machete cutterbar unit with air conveyor. The resulting lower stubble length that would be achieved, compared with the fixed platform model, would also tend to reduce the shatter loss caused by the impact cutting action.

11. RECOMMENDATIONS FOR FURTHER STUDY

Evidence has been presented to show the header is the most inefficient component of the combine, not only in soybeans, but also in other crops.

The economic magnitude of these grain and seed losses would justify the expansion of the header lab facility as follows:

- install vermin-proof plant storage space and crop conditioning equipment
- raise the header and track to enable installation of a gravity loss-catching system
- install straw-handling and vacuum clean-out equipment.

The facility could then be used to study header losses in other crops and some of the questions raised in this work. For example: reel index can be set in either of two ways - by varying forward speed or reel speed - is there an interactive effect on header loss between reel index and forward speed? What effect would variation in reel diameter and tine shape have on performance, especially with a floating cutterbar? In what ways could reel design be improved for operation in lodged conditions?

Further consideration should be given to shatter index and other engineering aspects of the soybean which may be relevant to the plant breeder.

With regard to field testing of header modifications, ways should be sought to further increase precision and speed of field loss analyses.

A narrow guard and sickle floating cutterbar should be evaluated.

The header loss variation across the width of the header should be studied.

A floating machete cutterbar - air conveyor header attachment, with

automatic overload protection and ground-contour following capabilities should be constructed and field tested.

The possibilities for reducing shatter loss by using multiple impact cutting should be explored. This could be accomplished by developing a continuous cutterbar which takes several bites at each stem (higher advance ratio), but which retains the ability to cut at ground level, at high forward speeds and without a reel.

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13. BIBLIOGRAPHY

1. Alexandrovich, F. N. Usovershenstvovanie ekstsentrikovogo motovila zhatki Zh BA - 3,5 (Improvement of harvester eccentric reel). Mekhaniz. Elektrif. sots. sel'Khoz. 23(5): 12, 13. 1965.
2. American Society of Agricultural Engineers. Terminology for combines and grain harvesting. ASAE Tentative Standard: ASAE S 343 T. Agr. Eng. Yearbook. ASAE, St. Joseph, Michigan. May 1971.
3. Annat, R. B. and Metcalfe, E. G. Combine with floating harvesting platform. U.S. Patent No. 3,312,048. (Filed in U.K. Mar. 13, 1963). April 4, 1967.
4. Baker, E. J. Combine reflections. Implement and Tractor 76(4): 35, 36. Feb. 1961.
5. Bledsoe, B. L. The design and experimental analysis of a rotary sickle for cutting and trajecting plant stems. Unpublished Ph.D. thesis. Library, Oklahoma State University, Stillwater, Oklahoma. Aug. 1969.
6. Bosoi, E. S. Ugol naklona lezviya segmenta rezhushehego apparata uborochnykh mashin (Angle of slope of the cutting edge of the knife of the cutting mechanism of harvesters). Sel' Khozmashina No. 5: 7-9. 1949.
7. Brown, W. T. and Vasey, G. H. Wheat harvester survey. A report sponsored by the Wheat Industry Res. Council, Commonwealth of Australia. University of Melbourne, Department of Agr. Eng., Parkville, Victoria. 1967.
8. Buchele, W. F. and Johnson, W. H. How to reduce soybean harvest losses. Iowa Certified Seed News 21(4): 5-7. 1967
9. Bunnelle, P. R., Jones, L. G. and Goss, J. R. Combine harvesting of small seed legumes. Agr. Eng. 35(8): 554-558. 1954.
10. Byg, D. M. and Johnson, W. H. Reducing soybean harvest losses. Ohio Report on Research and Development in Agriculture, Home Economics, and National Resources 55(1): 17, 18. 1970.
11. Caterpillar Tractor Co. Fifty years on tracks. Caterpillar Tractor Co., Peoria, Illinois. c1954.
12. Caviness, C. E. Effects of relative humidity on pod dehiscence in soybeans. Crop Science 4(4): 511-513. 1964.

13. Cooper, R. L. What's new in soybean row spacing and population?
Soybean News 20(3): 1, 2. 1969.
14. Culpin, C. The utilization and performance of combine harvesters,
1969. Farm mechanization studies No. 18. Ministry of
Agriculture Fisheries and Food, National Agr. Advisory Service,
(U.K.) April 1970.
15. Czukas, L. Anyagaramlas vizsgalata aratocseplogepeknél tekintettel
a teljesítménynövekedés lehetőségére (Examination of the flow of
the crop with combine harvesters with special respect to the
possible increase of performance). Jarmuvek, Mezogazdasagi
Gepek 11(3): 90-97. 1964.
16. Emirli, N. The nature and cause of shattering in soybeans.
Unpublished M.S. thesis. Library, Ohio State University,
Columbus, Ohio. 1956.
17. Everett, A. C. Soybean harvesting losses with the combine.
Unpublished M.S. thesis. Library, Iowa State University of
Science and Technology, Ames, Iowa. 1949.
18. Feller, R. Effects of knife angles and velocity on cutting of stalks
without a counter-edge. Jour. Agr. Eng. Res. 4(4): 277-293.
1959.
19. Finlayson, W. H. Rice headers inadequate for tough harvest. Power
Farming in Australia and New Zealand. 77(10): 14, 15. 1968.
20. Fischer-Schlemm, W. E. Der Einfluss des Watenwinkels auf die
Schneidhaltigkeit von Mahmesserklängen (The influence of the
angle of sharpening on the ability of the mower knives to
maintain their cutting efficiency). Grundle. Landtech. 5(2):
117-119. 1953.
21. Goldsmith, W. Impact, the theory and physical behaviour of colliding
solids. Edward Arnold (Publishers) Ltd., London. c1960.
22. Gorman, J. W. and Toman, R. J. Selection of variables for fitting
equations to data. Technometrics 8(1): 27-51. 1966.
23. Goss, J. R., Kepner, R. A. and Jones, L. G. Performance
characteristics of the grain combine in barley. Agr. Engr.
39(11): 697-702, 711. 1958.
24. Gustafson, D. J. The design and development of a combine attachment
for rowless agriculture. Unpublished M.S. thesis. Library,
Iowa State University of Science and Technology, Ames, Iowa.
1969.

25. Hebblethwaite, P. and Hephherd, R. Q. A detailed test procedure for combine harvesters. Suppl. Ann. Rep. Nat. Inst. Agr. Eng., 1960-61. Silsoe. S 365-371. 1961.
26. Heitshu, D. C. Soybean harvesting methods in Virginia. Agr. Eng. 9(7): 209-214. 1928.
27. Heyde, H. Landmaschinenlehre. Band 2 (Agricultural machinery theory. Volume 2). V.E.B. Verlag Technik, Berlin. 1965.
28. Hoag, D. L. Properties related to soybean shatter. Paper No. 71-341, presented at the 1971 Annual Meeting of ASAE, Pullman, Washington, June 1971. ASAE, St. Joseph, Michigan. 1971.
29. Howell, H. B. Cost of crop production in North Central Iowa. Iowa State University Cooperative Extension Service Bull. FM 1565 (Rev.) Nov. 1970.
30. Huitink, G. W. Cross-conveying in the combine header. Unpublished M.S. thesis. Library, Iowa State University of Science and Technology, Ames, Iowa. 1971.
31. Hunt, D. and Harper, R. W. Timeliness of soybean harvesting. Paper No. 67-615, presented at the 1967 Winter Meeting of ASAE, Detroit, Michigan, Dec. 1967. ASAE, St. Joseph, Michigan. 1967.
32. Hyzer, W. G. Engineering and scientific high-speed photography. Macmillan, New York. c1962.
33. Johnston, R. C. R. Crop behaviour during mowing. Jour. Agr. Eng. Res. 4(2): 193-203. 1959.
34. Kepner, R. A. Analysis of the cutting action of a mower. Agr. Eng. 33(11): 693-697, 704. 1952.
35. Koniger, R. Versuch einer Theorie des Scherenschnittes von Halmen (Attempt at a theory on the shearing of grass blades). Grndl. Landtech. 5(2): 96, 97. 1953.
36. Konstantinov, V. A. Skorost' vezaniia stblei kukuruzy bez protivoreza (The velocity of corn-stalk cutting without a counter-cutter). Mekhaniz. Elektrif. sots sel'Khoz. 23(4): 44, 45. 1965.
37. Lalor, W. F. Engineering and biological aspects of designing and using a selective flame weeder. Unpublished Ph.D. thesis. Library, Iowa State University of Science and Technology, Ames, Iowa. 1968.

38. Lamp, B. J., Johnson, W. H., Harkness, K. A. and Smith, P. E. Soybean harvesting - approaches to improved harvesting efficiencies. Ohio Agr. Exp. Sta. Res. Bull. 899. 1962.
39. Locati, N. C. Impact mowing apparatus and system. U.S. Patent No. 3,545,188. (Filed Sept. 16, 1968). Dec. 8, 1970.
40. Massey-Ferguson Inc. No sheaves in the field. Massey-Ferguson Inc., Detroit, Michigan. ca. 1964.
41. McCormick, J. M. and Salvadori, M. G. Numerical methods in FORTRAN. Prentice-Hall, New Jersey. c1964.
42. McKay, S. S. An historical review of Australian development of farm machinery. Agricultural Engineering Australia 2(2): 7-18. June 1971.
43. McKenzie, W. M. Fundamental aspects of the wood cutting process. For. Prod. Jour. 10(9): 447-456. 1960.
44. Mischke, C. R. An introduction to computer-aided design. Prentice-Hall, New Jersey. c1968.
45. Monsi, M. Untersuchungen uber den Mechanismus den Schleuderbewegung der Sojabohnen - Hulse (Research on the mechanism of dehiscence of the soybean pod). Jap. Jour. Bot. 12(3): 437-474. 1943.
46. Moore, J. W. Challenge ahead for soybeans. Soybean News 22(3): 2, 3. April 1971.
47. Moore, R. S. China doctor - the life story of Harry Willis Miller. Pacific Press Publ. Assoc., Mountain View, California. c1969.
48. Moraghan, B. J. Plant characteristics related to yield response of unselected lines of soybeans in various row widths and plant populations. Unpublished Ph.D. thesis. Library, Iowa State University of Science and Technology, Ames, Iowa. 1970.
49. Nave, W. R., Tate, D. E. and Butler, B. J. Combine headers for soybeans. Paper No. 70-629, presented at the Winter meeting of ASAE, Chicago, Illinois. Dec. 1970. ASAE, St. Joseph, Michigan. 1970.
50. Neal, A. E. and Cooper, G. F. An approach to laboratory testing of harvest equipment. Paper No. 67-147, presented at the 1967 Joint Annual Meeting of the ASAE - CSAE, Saskatoon, Saskatchewan, June 1967. ASAE, St. Joseph, Michigan. 1967.

51. Nyberg, C. Highlights in the development of the combine. Agr. Eng. 38(7): 528, 529, 535. 1957.
52. Orechov, N. I. and Tarasenko, A. P. O poteriakh za zhatvennymi agregatami pri rabote na povyshennykh skorostiakh (Losses of harvesting machines operated at increased speeds). Mekhaniz. Elektrif. sots Sel'Khoz. 22(5): 22-24. 1964.
53. Park, J. K. Combine cutting and feeding mechanisms in the Southeast. Agr. Res. Serv., USDA, and South Carolina AES, Production Res. Rep. No. 68. Feb. 1963.
54. Park, J. K. and Webb, B. K. Seed harvesting in the Southeast. South Carolina AES Bulletin 461. July, 1958.
55. Park, J. K. and Webb, B. K. Soybean harvesting losses in South Carolina. South Carolina AES Circular 123. 1959.
56. Partridge, M. Early agricultural machinery. Hugh Evelyn Ltd., London. c1969.
57. Phillips, C. M. Pneumatic attachment for grain harvesting machines. U.S. Patent No. 2,670,586. (Filed Nov. 7, 1951). Mar. 2, 1954.
58. Prince, R. P., Bartok, J. W. and Bradway, D. W. Shear stress and modulus of elasticity of selected forages. Trans. ASAE 12(4): 426-429. 1969.
59. Probst, A. H. Fifty years of soybean variety improvement. Soybean Digest 30(11): 66-70. 1970.
60. Quick, G. R. Aerodynamic grain handling system. U.S. Patent No. 3,555,790. (Filed Aug. 5, 1968). Jan. 19, 1971.
61. Quick, G. R. Combine harvesters for soybean research. Unpublished M.S. thesis. Library, Iowa State University of Science and Technology, Ames, Iowa. 1970.
62. Quick, G. R. and Taylor, J. C. Photo-instrumentation in combine research. Paper No. 71-510, presented at the Annual Meeting of ASAE, Pullman, Washington. June 1971. ASAE, St. Joseph, Michigan. 1971.
63. Reineke, L. H. Pendulum cutting test standardization, and pertinent cutting fundamentals. For. Prod. Jour. 10(10): 542-553. 1960.
64. Reznik, N. E. Klassifikatsiia rezhushchikh apparatov (Classification of the cutting apparatus). Mekhaniz. Elektrif. sots. sel'Khoz. 28(2): 13-17. 1970.

65. Romer, G. and Urban, W. Die Forderung von halmgut durch Forderschnecken (The movement of fodder stalks by screw conveyor). Landtechnische Forschung 5(2): 48-52. 1955.
66. Schertz, C. E. Rotary cutters and cylindrical rollers for gathering function in harvest of soybeans. Paper No. 70-628, presented at the Winter Meeting of ASAE, Chicago, Illinois. Dec. 1970. ASAE, St. Joseph, Michigan. 1970.
67. Scott, W. O. and Aldrich, S. R. Modern soybean production. The Farm Quarterly, Cincinnati, Ohio. 1970.
68. Schueler, H. C. Harvester. U.S. Patent No. 1,794,646. (Filed Feb. 29, 1928). Mar. 3, 1931.
69. Schultze, K. H. Uber den Schneidvorgang an Grashalmen (On the process of cutting grass stalks). Grndl. Landtech. 5(2): 98-116. 1953.
70. Semenov, V. F. Otgib steblei rezhushchimi apparatami uborochnykh mashin (Bending stems by cutting apparatus of the harvester). Mekhaniz. Elektrif. sots. sel'Khoz. 23(5): 49, 50. 1965.
71. Sjogren, J. W. Methods and machinery for harvesting soybeans. Virginia Polytechnic Institute Bull. 319. Jan. 1939.
72. Soybean Digest. Blue book issue. Soybean Digest 31(6): 90. 1971.
73. Steel, R. G. D. and Torrie, J. H. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill Book Company Inc., New York. c1960.
74. Stroppel, T. Zur Systematik der Technologie des Schneidens (On the systematics of the technology of cutting). Grndl. Landtech. 5(2): 120-134. 1953.
75. Tate, D. E. Combine header designed for soybeans. Unpublished M.S. thesis. Library, The University of Illinois, Urbana, Illinois. 1971.
76. Thompson, H. E. and Herman, J. C. Profitable soybean production. Second printing. Iowa State University of Science and Technology Cooperative Ext. Serv. PM441. Feb. 1970.
77. Thompson, L. M. Iowa agriculture, world food needs and educational response. Iowa State University Center for Agricultural and Economic Development Bulletin AAC 156. Nov. 1968.

78. Turbin, B. G., Lurie, A. B., Grigoriev, S. M., Ivanovich, E. M. and Melnikov, S. V. Sel'skokhoziaistvennyye mashiny, teoriia i tekhnologicheskii raschet (Farm machines theory and technological design). 2nd edition. Izdatelstvo "Mashinostroenie", Leningrad. 1967.
79. Wealti, H., Turnquist, P. K. and Matter, V. E. Harvesting techniques for reducing grain sorghum losses. Paper No. 69-633, presented at the Winter Meeting of ASAE, Chicago, Illinois. Dec. 1969. ASAE, St. Joseph, Michigan. 1969.
80. Weber, C. R., and Fehr, W. R. Seed yield losses from lodging and combine harvesting in soybeans. Agron. Jour. 58(3): 287-289. 1966.
81. Wheelhouse, F. Digging stick to rotary hoe - men and machines in rural Australia. Cassell Australia Ltd., Melbourne. c1966.
82. Wileman, R. H. Field tests of the combine in Indiana. Agr. Eng. 8(5): 118. 1927.
83. Woodruff, K. A. Evaluation of header height control mechanisms. Unpublished M.S. thesis. Library, Iowa State University of Science and Technology, Ames, Iowa. 1971.

14. APPENDIX

Table A-1. Amsoy seed weight distributions. ^a Data plotted in Figure 19.

Interval Range (g)	Interval Range (mg.)	Frequency f	Mid Interval Scores (mg)	1/10 Deviation d	fd	fd ²	E _f	(f-E _f) ²
0.080-0.089	80-89	1	85	7	7	49	—	—
0.090-0.099	90-99	24	95	6	144	865	86.17	3068.84
0.100-0.109	100-109	113	105	5	565	2821	86.17	718.24
0.110-0.119	110-119	90	115	4	360	1440	86.17	14.44
0.120-0.129	120-129	100	125	3	300	900	86.17	190.44
0.130-0.139	130-139	67	135	2	134	268	86.17	368.64
0.140-0.149	140-149	87	145	1	87	87	86.17	0.64
0.150-0.159	150-159	72	155	0	0	0	86.17	201.69
0.160-0.169	160-169	66	165	-1	-66	66	86.17	408.04
0.170-0.179	170-179	75	175	-2	-150	300	86.17	148.84
0.180-0.189	180-189	111	185	-3	-333	999	86.17	615.04
0.190-0.199	190-199	112	195	-4	-448	1792	86.17	665.64
0.200-0.209	200-209	61	205	-5	-305	1525	86.17	633.04
0.210-0.219	210-219	20	215	-6	-120	720	86.17	4382.44
0.220-0.229	220-229	3	225	-7	-210	147	—	—
Σ Totals		1258		0	11,979			12883.56

^a COMPUTATIONS :

- A. Determination of mean and standard deviation
Grouped Distribution, Weight Intervals: 0.01 g
Amsoy, 7.5% M C 1/11/68 - K.L.

Average Bean Weight

$$W = W_0 + C \frac{\sum fd}{\sum f}$$

$$= 155 + 10 \left(\frac{-35}{1258} \right) = 155 - .228$$

$$= 154.72 \text{ mg}$$

$$s = 10 \sqrt{\frac{\sum fd^2}{\sum f} - \left(\frac{\sum fd}{\sum f} \right)^2}$$

$$= 10 \sqrt{\frac{11,979}{1,258} - \left(\frac{-35}{1258} \right)^2}$$

$$= 30.9 \text{ mg}$$

- B. Chi-square test for goodness of fit

$$\chi^2 = \frac{\sum (f - E_f)^2}{E_f} = \frac{12883.56}{86.17} = 149.46$$

H₀: That the seed weight distribution is uniform randomly distributed

$$\alpha = 0.01 \quad n = 13$$

$$\chi^2_{\text{critical}} = \chi^2_{0.01, n-2} = \chi^2_{0.01, n-2} = 24.72$$

$$\chi^2_{\text{test}} > \chi^2_{\text{critical}}$$

Decision: Accept H₀. The hypothesis that the data was uniform randomly distributed between the 95 and 215 mg range could not be rejected at the 1% level of significance, using the chi-square test for goodness of fit.

Table A-2. Soybean yield calculator; determination of equivalent bushel weight^a at 13% MC for samples of given moisture content^b (67).

Actual Moisture Content %	Pounds Equal to 1 Bu @ 13%	Actual Moisture Content %	Pounds Equal to 1 Bu @ 13%
8.0	56.74	14.5	61.05
8.5	57.05	15.0	61.41
9.0	57.36	15.5	61.77
9.5	57.68	16.0	62.14
10.0	58.00	16.5	62.51
10.5	58.33	17.0	62.89
11.0	58.65	17.5	63.27
11.5	58.98	18.0	63.66
12.0	59.32	18.5	64.05
12.5	59.66	19.0	64.44
13.0	60.00	19.5	64.84
13.5	60.35	20.0	65.25
14.0	60.70	20.5	65.66

^a1 U.S. bushel = 1.244 cu.ft. 1 Imp. bushel = 1.03 U.S. bushel.

^bWhen yield weight and moisture content of sample are known, convert by dividing by the appropriate weight figure in right hand column to obtain equivalent number of bushels at 13.0% moisture content.

Sample calculation:

3400 lb./acre yield @ 16.5% MC

Equivalent yield = $\frac{3400}{62.51}$ = 54.39 bu/acre @ 13% MC.

Table A-3. Soybean plant vibrational response^a.

Mode of flexural vibration of stem	Position of nodes	kℓ in.	Predicted frequency, Hz
Fundamental	0.0	1.875	3.98
Second harmonic	0.0, 0.774ℓ	4.694	24.9
Third harmonic	0.0, 0.500ℓ, 0.868ℓ	7.855	69.8
Fourth harmonic	0.0, 0.356ℓ, 0.644ℓ, 0.906ℓ	10.996	136.5

^aStem response determined from continuous cantilever beam vibration theory. Vibrational mode frequency (Hz):

$$f_n = \frac{1}{2\pi} \cdot \frac{(k\ell)^2}{\ell^2} \cdot \sqrt{\frac{EI G}{w}}$$

where ℓ = span, in this case 30 in.

k = coefficient, determined from beam theory

EI = flexural rigidity of bean stem; in this case, for a stem diameter of 0.25 in. at the mounting, 58 lb. in.² (from Instron tests).

w = 0.001 lb./in., weight/unit length.

The following assumptions were involved:

- (1) The motion is planar. The beam is elastic and rigidly clamped at the mounting.
- (2) The stem (beam) is homogeneous, of constant cross section and its weight uniformly distributed.
- (3) Pod motion is ignored and pod weight is lumped in with weight of stem.

Table A-4. Shatter of soybean pods induced by centrifugation.^a Data plotted in Figure 26.

Variety and moisture	Centrifugal force, calculated from $\bar{m}\omega^2 r$, lb.		\bar{w} Mean seed Weight, lb.	Acceleration G's ^b	
	10%	50%		10%	50%
	shattered	shattered		shattered	shattered
Amsoy 9.9% MC	0.125	0.172	0.184	298	411
Amsoy 13.5% MC	0.191	0.387	0.192	451	916
Corsoy 13.0% MC	0.218	0.457	0.156	634	1328

^aEach data point which was plotted in Figure 26 represented the shattered seed accumulated at a given disc speed, with 20 to 30 pods in the disc-clamps per loading.

^bBased upon the equation:

$$\text{Acceleration (G's)} = \frac{454 (\bar{m}\omega^2 r)}{\bar{w}} .$$

Table A-5. Results of statistical analysis for selection of sampling frame size and number^a, etc., using 1967 data from a Lovebar vs. standard header test (see Table A-28).

Number of replications, or blocks ^b	Number of sub-samples or frames ^c	Relative precision percent
4	10	100 ^d
6	4	123
8	4	150
4	8	94
4	6	86
4	4	74
4	2	52
2	2	26

^aErbach, D. C. ISU, USDA-ARS, Ames, Iowa. Notes on analysis for selection of sampling frame size and number, etc. Private communication. April 16, 1968.

^bThe initial experiment was laid out as shown in Figure 103. A block consisted of one run with the combine through a plot. Within this block the sampling frames were thrown down across the middle two rows in the 10 ft (4 row) plots.

^cBasic frame size was 1/10,000 acre, or 10.45 in. x 60 in. inside dimensions. In a separate analysis, no statistically significant difference was detected between using the basic frame size and a frame size two to four times larger, with the same number of sub-samples in each case.

^dThe various treatment combinations of number of reps x number of frames were compared with the 4 x 10 experiment as the standard. The relative precision was estimated by taking the ratio of the variance of a treatment mean and comparing it with the variance of the standard treatment mean. To use more replications involves more field plot area, and more combine work. To use more sub-samples with the same number of replications involves counting more bean losses. The choice was decided on the basis of the number of machines or machine variables which had to be tested.

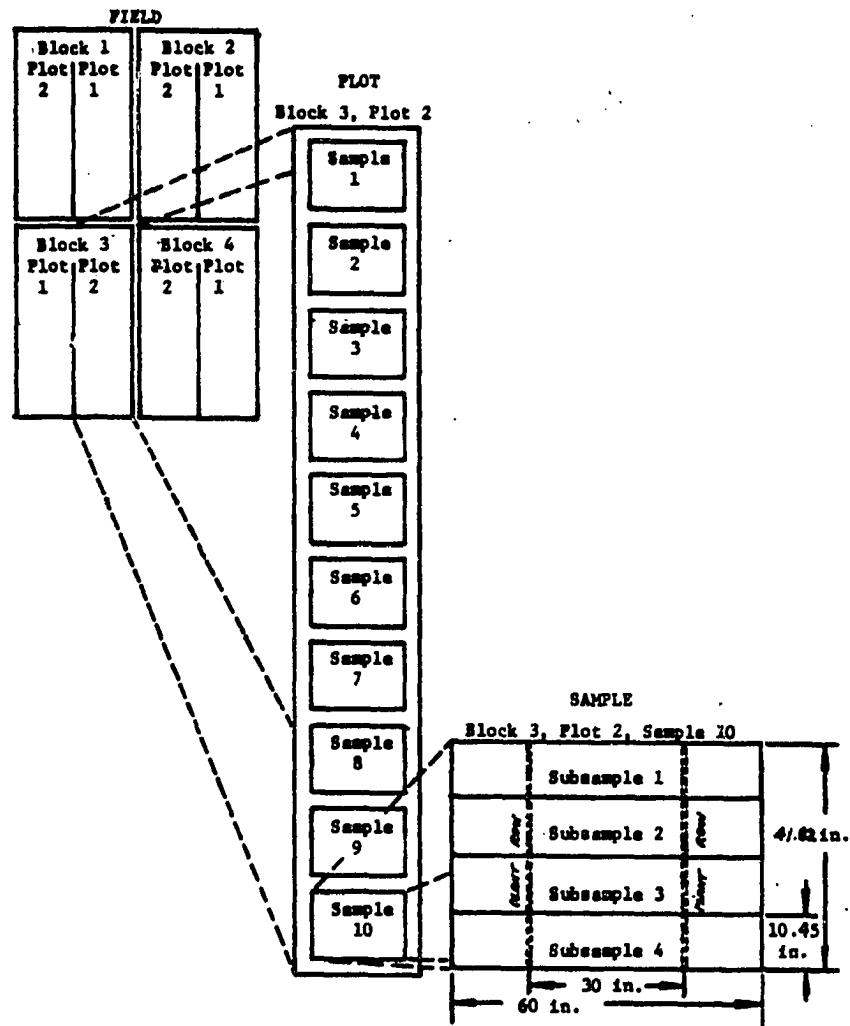


Figure 103. Field experimental layout for analysis for frame size selection and comparison between Lovebar and standard headers.

Table A-6. Regression^a of lab test data on field data, simultaneous header testing in three soybean varieties and combine speeds. Data are plotted in Figure 37.

x, Field header loss, ranked percent	y, Lab header loss, percent	\hat{y} , Predicted lab header loss, percent	Confidence belt: $\pm u$, percent ^b
1.09	1.95	1.5806	.6889
1.37	2.58	1.7875	.6608
2.25	1.63	2.4375	.5781
2.69	2.28	2.7626	.5409
2.72	2.46	2.7847	.5385
2.79	3.25	2.8364	.5329
3.00	2.72	2.9916	.5168
3.40	3.20	3.2870	.4888
3.86	2.70	3.6268	.4614
7.09	7.76	6.0128	.4774
7.64	6.93	6.4191	.5146
8.44	8.08	7.0101	.5796
9.40	6.83	7.7192	.6705
9.54	7.26	7.8226	.6845
9.83	7.80	8.0369	.7145
10.27	8.05	8.3619	.7608

^aLinear regression: $\hat{y} = 0.7755 + 0.7387 x$, $n = 16$

$$s_{y/x} = 0.7850\%$$

^bConfidence limits on the mean: 95% C.L. (\hat{y}) = $\hat{y} \pm u$,

where
$$u = t_{0.025, n-2} \cdot s_{y/x} \sqrt{\frac{1}{n} + \frac{(x-\bar{x})^2}{\sum (x-\bar{x})^2}}$$

$$t_{0.025, 14} = 2.145$$

Table A-7. Least-squares regression OMNITAB program. Exponential function for Figure 23.

OMNITAB REGRESSIONS

OMNITAB REGRESSIONS

POLYNOMIAL FIT OF DEGREE 1 TO THE FUNCTION IN 7.

THE INDEPENDENT VARIABLE (X) IS IN COLUMN 2.

8 NON-ZERO WEIGHTS APPEAR IN COLUMN 1.

TERM OF DEGREE	COEFFICIENT	COEF. STD. DEV.	T-VALUE
0	-3.5900660E 00	2.4942070E-01	-1.4393697E 01
1	8.2561213E-01	4.9392667E-02	1.6715271E 01

NOTE. T-VALUE MAY NOT BE A VALID T TEST IF THE X MATRIX IS NOT ORTHOGONAL.

STANDARD DEVIATION 3.2010090E-01

THE INVERSE OF THE X'X MATRIX OF THE NORMAL EQUATIONS

-0.0714346E-01	
-1.071429E-01	2.3809548E-02

THE SQUARE ROOT OF THE DIAGONALS IN THE ABOVE MATRIX

7.7519412E-01 1.5433343E-01

THE VARIANCE-COVARIANCE MATRIX OF THE REGRESSION COEFFICIENTS

6.2210623E-02	
-1.0575356E-02	2.4396346E-03

THE SQUARE ROOT OF THE DIAGONALS IN THE VARIANCE-COVARIANCE MATRIX

2.45-2070E-01 9.9392667E-02

THE A(1,J) MATRIX

3.5555325E-01	
-5.9436556E-01	1.5430343E-01

GRAM DETERMINANT 2.0588195E-01

ANALYSIS OF VARIANCE

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F
TOTAL	2.9368759E 01	8	3.6710949E 00	
TERM OF DEGREE	0 1.2533647E-01	1	1.2533647E-01	0.03
RESIDUAL	2.9243423E 01	7	4.1776314E 00	
TERM OF DEGREE	1 2.8628647E 01	1	2.8628647E 01	279.41
RESIDUAL	6.1477661E-01	6	1.0246277E-01	
TOTAL REDUCTION	2.8753983E 01	2	1.4376991E 01	140.31

```

FIXED 4
FORMAT A (12X,F3.0,8X,F7.4)
FORMAT C (2X,2F5.2)
RESET NRMAT 14
ADD 1. 1 1
1/ LOGE OF 3 AND STORE IN 7
2/ POLYFIT 7 1 2 1 4 5
3/ SUBTRACT 5 7 6
4/ EXP OF 6 AND STORE IN 8
5/ EXP OF 5 AND STORE IN 9
6/ PRINT 2 3 8 9
READ A 14 CARDS 2 3
14 DATA CARDS READ BUT NOT LISTED
EXECUTE 1 6
RESET NRMAT 7
READ A 7 CARDS 2 3
7 DATA CARDS READ BUT NOT LISTED
EXECUTE 1 6
RESET NRMAT 6
READ C 6 CARDS 2 3
6 DATA CARDS READ BUT NOT LISTED
EXECUTE 1 6
RESET NRMAT 13
READ C 13 CARDS 2 3
13 DATA CARDS READ BUT NOT LISTED
EXECUTE 1 6
RESET NRMAT 8
READ C 8 CARDS 2 3
8 DATA CARDS READ BUT NOT LISTED
EXECUTE 1 6
STOP

```

COLUMN 2	COLUMN 3	COLUMN 8	COLUMN 9
X, CUTTING HEIGHT, IN.	%FEED LEFT	Y	Y-Y
1.0000	0.0500	0.0630	0.7935
2.0000	0.1000	0.1439	0.6951
3.0000	0.5000	0.3285	1.5221
4.0000	0.9000	0.7500	1.1990
5.0000	2.2000	1.7125	1.2846
6.0000	4.3000	3.9102	1.0997
7.0000	9.2000	8.9280	1.0305
8.0000	13.9000	20.3852	0.6819

$$\ln \hat{y} = \ln \hat{A} + \hat{B} x, \hat{y} = \hat{A} e^{\hat{B} x}$$

$$\hat{A}' = -3.5901, \hat{A} = 0.0273$$

$$\hat{B} = 0.8256$$

$$\therefore \hat{y} = 0.0273 e^{0.8256 x}$$

$$S_{y/x} = 1.278 \%$$

Table A-8. High-speed photo-instrumentation:- reduction of data from film. Quadratic interpolation of the end points.^a

Interpolation of	$\dot{\underline{X}} _{t_1}$	$\ddot{\underline{X}} _{t_1}$
Initial point $t_1 = t - \Delta t$	$\frac{-\underline{X} _{t+\Delta t} + 4\underline{X} _t - 3\underline{X} _{t-\Delta t}}{2\Delta t}$	$\frac{\underline{X} _{t+\Delta t} - 2\underline{X} _t + \underline{X} _{t-\Delta t}}{(\Delta t)^2}$
End point $t_1 = t + \Delta t$	$\frac{3\underline{X} _{t+\Delta t} - 4\underline{X} _t + \underline{X} _{t-\Delta t}}{2\Delta t}$	$\ddot{\underline{X}} _{t+\Delta t} = \ddot{\underline{X}} _t = \ddot{\underline{X}} _{t-\Delta t}$

^aFor evenly spaced pivotal points (41), let the function $p(T)$ be a paraboloid passing through the points $\underline{X}|_{t-\Delta t}$, $\underline{X}|_t$ and $\underline{X}|_{t+\Delta t}$

$$\text{i.e. } p(T) = A_0 + A_1(T-t) + A_2(T-t)^2$$

$$\text{where } A_0 = \underline{X}|_t$$

$$A_1 = \frac{\underline{X}|_{t+\Delta t} - \underline{X}|_{t-\Delta t}}{2(\Delta t)}$$

$$A_2 = \frac{\underline{X}|_{t+\Delta t} - 2\underline{X}|_t + \underline{X}|_{t-\Delta t}}{2(\Delta t)^2}$$

$$p'(T) = 2A_2(T-t) + A_1$$

$$p''(T) = 2A_2$$

As an alternative to quadratic interpolation, a least-square regression on the raw data might be used, but the resultant smoothing may "cover" important regions and the loss of information would be accentuated in the successive differentiations.

Table A-9. Results and regression analysis^a output for 1969 field header loss characteristics trial.

b. IDENT.	HEADER LOSSES, PERCENT. RAW & PREDICTED (MODEL 2) DATA								NET POTENTIAL YIELD LB./ACRE
	SHATTER AND PRE-HARVEST		STALK AND LODGED		STUBBLE		TOTAL HEADER (INCL. PRE-HARVEST)		
	MEASURED	PREDICTED	MEASURED	PREDICTED	MEASURED	PREDICTED	MEASURED	PREDICTED	
111	2.22	2.1407	4.70	4.2324	0.0	0.6286	6.92	7.0018	2863.28
2	3.23	2.2047	3.70	4.3439	0.26	0.4559	7.19	7.0045	2851.17
3	2.59	2.5862	7.71	5.8173	1.62	1.4256	11.92	9.8291	2367.09
4	4.64	3.2852	8.84	8.6526	3.19	3.5379	16.67	15.4757	2525.36
121	1.04	1.4137	3.48	4.3449	0.27	0.8106	4.79	6.5693	2757.69
2	1.13	1.4777	6.65	4.4564	0.0	0.6379	7.78	6.5720	2369.21
3	1.57	1.8592	3.97	5.9298	0.74	1.6076	6.28	9.3966	2566.33
4	1.70	2.5582	7.07	8.7651	2.17	3.7199	10.94	15.0432	2825.00
131	1.84	1.4117	4.76	4.7330	0.0	0.5701	6.60	6.7149	3025.40
2	2.25	1.4757	5.10	4.8445	0.75	0.3974	8.10	6.7176	3577.18
3	2.27	1.8572	7.99	6.3179	0.29	1.3671	10.55	9.5423	2621.73
4	2.61	2.5562	7.15	9.1532	6.87	3.4794	16.63	15.1888	2716.42
141	1.25	2.1347	2.88	5.3968	0.29	0.0929	4.12	7.4386	2600.58
2	1.35	2.1987	4.39	5.5083	0.51	0.2656	6.25	7.4414	2972.33
3	1.91	2.5802	8.00	6.9817	0.0	0.7041	9.91	10.2660	2714.23
4	2.99	3.2792	12.19	9.8169	1.56	2.8164	16.74	15.9125	2696.53
211	1.74	SAME AS BLOCK 1	4.31	SAME AS BLOCK 1	0.90	SAME AS BLOCK 1	6.95	SAME AS BLOCK 1	2541.53
2	1.45		4.35		0.90		6.70		3179.26
3	1.89		4.74		1.19		7.82		2739.33
4	3.47		9.95		4.55		17.97		2492.28
221	1.34		6.43		0.84		8.61		2719.82
2	1.53		3.65		2.63		7.81		2261.33
3	1.38		3.78		1.02		6.18		3204.07
4	2.54		5.34		4.34		12.22		2876.73
231	2.22		4.99		0.18		7.39		3116.77
2	1.23		5.74		0.17		7.14		3280.81
3	1.76	8.96	1.17	11.89	2616.14				
4	2.81	12.03	3.74	18.58	2461.69				
241	2.60	5.78	0.43	8.81	2659.22				
2	2.40	4.98	0.0	7.38	2315.55				
3	4.54	4.69	1.41	10.64	2579.60				
4	2.55	10.29	1.61	14.45	2858.46				

^aThe original regression equations (Model 1) included stubble length x combine speed interaction term, but this was found not significant (at the 10% level) so that Model 2, a quadratic form without interaction (Equation 6-1), was fitted and plotted instead.

^bIdentification: first column=block identification; second digit=combine nominal speed, code: 1=4 mph, 2=3 mph, 3=2 mph, 4=1 mph; third digit=nominal mean stubble length, code: 1=3 in., 2=4-1/2 in., 3=6 in., 4=7-1/2 in.

Referring to Table A-9, the least-squares regression equations on component losses are:

$$\hat{\pi}_{1,1} = 3.8462^{**} - 0.4123^{**}V + 0.1588V^2 - 1.8145L_1 + 0.3625^{*}L_1^2,$$

$$S_{\pi_{1,1}}/V, L_1 = 0.7167\%$$

$$\hat{\pi}_{1,2} = 5.6459^{**} - 1.9313^{**}V + 0.6809V^2 - 0.3009L_1 + 0.1378L_1^2,$$

$$S_{\pi_{1,2}}/V, L_1 = 1.7625\%$$

$$\hat{\pi}_{1,4} = 1.3394^{**} - 1.8865^{**}V + 0.5712V^2 + 0.8157L_1 - 0.2112L_1^2,$$

$$S_{\pi_{1,4}}/V, L_1 = 1.0370\%.$$

Table A-10. Header lab test to assess the effect^a of forward speed (rate of advance) on header losses in variety Amsoy at 13% MC.

Speed V mph	Header losses, raw data			Total %
	Shatter %	Stalk %	Stubble %	
1.00	5.66	0.82	1.37	7.85
1.50	4.56	1.37	1.40	7.33
1.90	2.87	2.03	1.90	6.80
2.00	3.88	1.56	1.46	6.90
2.05	2.80	1.40	1.60	5.80
2.10	2.72	1.00	1.97	6.69
2.25	4.46	0.96	1.36	6.78
2.30	3.40	1.70	2.40	6.50
2.45	3.20	1.96	2.66	7.90
2.50	3.32	1.18	2.40	6.90
2.60	3.30	2.50	1.50	7.30
2.65	3.55	2.66	2.62	8.83
2.90	3.40	1.80	1.20	6.40
3.00	3.47	1.95	1.56	6.98
3.05	3.18	2.16	2.56	7.90
3.10	2.90	2.10	2.80	7.80
3.45	4.40	2.40	2.80	9.60
3.50	3.72	1.50	1.60	6.82
3.75	3.00	2.80	2.70	8.50
4.35	2.95	2.40	2.90	8.10
4.55	3.20	1.50	3.00	7.70
4.95	2.10	2.40	3.40	7.90
5.45	3.50	1.85	3.40	8.75
7.10	7.56	1.46	3.12	12.14

^aThe characteristic curves in Figure 42 were plotted from the least-squares regression equations (selected models with lowest $|C_p-p|$ statistic, as in Equation 5-8):

$$\text{Shatter loss: } \hat{\pi}_{1,1} = \frac{5.1151}{V} + 0.4718V, S_{\pi_{1,1}/V} = 1.3628\%$$

$$\text{Stalk loss: } \hat{\pi}_{1,2} = 0.9687 + 0.2347V, S_{\pi_{1,2}/V} = 1.0964\%$$

$$\text{Stubble loss: } \hat{\pi}_{1,4} = \frac{-3.0451}{V^2} + \frac{4.2231}{V} + 0.0804V^2, S_{\pi_{1,4}/V} = 1.0765\%$$

$$\text{Total loss: } \hat{\pi}_1 = \frac{4.1956}{V} + 2.4779 + 1.1275V, S_{\pi_1/V} = 0.4143\%$$

Table A-11. Influence of moisture content (MC) on header loss^a, header lab test on variety Amsoy.

Moisture content % W.B.	Shatter loss %	Stalk loss %	Stubble loss %	Total loss %
7.0	8.2	3.0	0.8	12.3
7.2	15.6	1.5	0.5	17.2
7.5	9.8	1.2	1.5	12.5
8.0	5.1	5.0	2.9	13.0
9.0	5.1	3.6	2.1	12.7
9.2	7.6	3.4	2.1	13.1
9.5	7.4	2.5	0.5	10.4
11.0	7.3	2.3	2.3	11.9
11.7	5.5	0.9	1.2	7.7
12.0	6.1	1.8	1.5	9.4
12.5	2.8	1.9	0.5	5.2
13.0	3.0	1.1	1.5	5.6
13.2	3.0	2.3	1.4	6.7
13.5	4.2	1.0	3.5	8.8
14.4	5.0	3.0	1.5	9.5
15.0	4.4	3.1	2.0	9.5
18.8	2.4	2.9	1.4	6.7
28.0	1.9	2.2	1.5	5.6
32.0	2.1	1.8	1.2	5.1

^aThe characteristic curves in Figure 43 were plotted from the following least-squares regression equations:

$$\text{Shatter loss: } \hat{\pi}_{1,1} = \frac{362.4229}{(\text{MC})^2} + \frac{22.9128}{\text{MC}}, S_{\pi_{1,1}/\text{MC}} = 0.6974\%$$

$$\text{Stalk loss: } \hat{\pi}_{1,2} = \frac{6.7251}{\text{MC}} + 1.7447, S_{\pi_{1,2}/\text{MC}} = 1.0554\%$$

$$\text{Stubble loss: } \hat{\pi}_{1,4} = \frac{-6.4885}{(\text{MC})^2} + 1.7313, S_{\pi_{1,4}/\text{MC}} = 0.9867\%$$

$$\text{Total loss: } \hat{\pi}_1 = \frac{416.4636}{(\text{MC})^2} + \frac{19.4411}{\text{MC}} + 4.2565, S_{\pi_1/\text{MC}} = 0.7962\%$$

Using exponential model:-

$$\text{Total loss: } \hat{\pi}_1 = 15.71 e^{-0.0406(\text{MC})}, S_{\pi_1/\text{MC}} = 1.288\%$$

Table A-12. 1969 Test on the influence of weeds on header losses and yield, variety Amsoy.^a

A. Weedy plot , 16% MC :

EXPT INPUT DATA^b

4.3560 2300.0000 29.2000 120.0000 435.6001

HEADER LOSS DATA EXPRESSED AS PERCENTAGES

PLOT IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE
1101	0.0000	2.5386	0.0000	0.0000	2.5386	2226.52
1102	0.0569	0.0000	0.0000	0.0000	0.0569	2171.23
1103	0.0000	0.7919	0.0000	0.3960	1.1879	2196.09
1104	0.0000	0.2000	0.0000	0.0000	0.2000	2174.35

B. Weed-free plot, 16% MC :

EXPT INPUT DATA

4.3560 2300.0000 39.2000 60.0000 435.6001

HEADER LOSS DATA EXPRESSED AS PERCENTAGES

PLOT IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE
1201	2.1926	5.9103	0.0000	1.0132	9.1161	2574.71
1202	0.0000	2.3457	0.0000	0.5413	2.8870	2409.56
1203	0.5261	4.0551	0.0000	0.5289	5.1102	2466.02
1204	2.5091	4.6887	0.0000	2.6792	9.8770	2596.45

^aData printed out by program detailed in section 5.5.^bExperiment input data included respectively FRASI, BEAPP, PREHAR, TRUCOL, PLOTSI.

Table A-12. (Continued)

C. Weedy plot, 13.5% MC :

EXPT INPUT DATA

4.3560 2400.0000 32.5000 100.0000 435.6001

HEADER LOSS DATA EXPRESSED AS PERCENTAGES

PLOT IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE
2101	0.0000	1.9470	0.0000	0.3894	2.3364	2140.00
2102	0.0000	4.1541	0.0000	1.1329	5.2870	2206.67
2103	0.0000	4.5489	0.0000	0.3791	4.9280	2198.33
2104	0.0000	0.9870	0.0000	0.0000	0.9870	2110.83

D. Weed-free plot, 13.5% MC :

EXPT INPUT DATA

4.3560 2400.0000 40.5000 30.0000 435.6001

HEADER LOSS DATA EXPRESSED AS PERCENTAGES

PLOT IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE
2201	2.2682	2.9036	0.0000	1.3664	6.5382	2439.50
2202	0.5462	7.4940	0.0000	0.8327	8.8729	2502.00
2203	0.0459	5.2418	0.0000	5.0780	10.3656	2543.67
2204	0.0000	1.0807	0.0000	0.3602	1.4409	2313.33

Table A-13. Computation of reel parameters, using zero horizontal velocity of reel bar at entry into crop criterion.

```

$JOB          I4244GRQUICK ,TIME=5,PAGES=10
C
C ***** PURPOSE OF THE PROGRAM IS TO PLOT OUT *****
C          REEL PARAMETERS WHICH ARE DEPENDANT ON
C          REEL INDEX
C *****
C          SET CUTTING HEIGHT AT 4" ,CROP HEIGHT 36" ,
C          REEL DIA. 42.5" , SIX BAR REEL *****
C
1  DIMENSION RINDEX(500),DELTAX(500),XLAR(5),YLAB(5),
2  SD(50) , R(50) , PHI(500), E(50) , HM(100)
3  RADIUS = 21.25/ 12.0
4  H = 0.3333
5  XL = 3.00
6  PI = 3.141259
7  N = 6
8  WRITE (6,20)
9  20 FORMAT (5X , ' R.I.    DELTA X    C.I.    HT.,IN ',/ )
10 J=1
11 DO 25 I=100,400,10
12 G=1
13 RINDEX(I)=G/100.
14 PHI(I)= ARSIN ( 1.0 / RINDEX(I) )
15 DELTAX(I)=RADIUS/RINDEX(I)*(PHI(I) - PI /2.+(RINDEX(I)**2-1)**0.5)
16 R(J)=RINDEX(I)
17 D(J)=DELTAX(I)
18 E(J) = N * D(J) / (2.0* PI * RADIUS ) * R(J)
19 HM(J) =(RADIUS/R(J) *XL - H - RADIUS ) * 12.0
20 WRITE (6,90 ) R(J) , D(J) , E(J) , HM(J)
21 90 FORMAT ( 4F10.3 )
22 J=J+1
23 25 CONTINUE
24 STOP
25 END

```

	SENTRY		
R.I.	DELTA X	C.I.	HT.,IN
1.000	0.000	0.000	32.000
1.100	0.046	0.027	30.069
1.200	0.115	0.074	28.459
1.300	0.188	0.131	27.097
1.400	0.259	0.196	25.929
1.500	0.327	0.265	24.917
1.600	0.391	0.338	24.032
1.700	0.451	0.414	23.250
1.800	0.507	0.492	22.556
1.900	0.558	0.572	21.935
2.000	0.607	0.654	21.375
2.100	0.651	0.738	20.869
2.200	0.693	0.822	20.409
2.300	0.732	0.908	19.990
2.400	0.768	0.994	19.605
2.500	0.802	1.081	19.250
2.600	0.834	1.169	18.923
2.700	0.864	1.258	18.621
2.800	0.892	1.347	18.340
2.900	0.918	1.436	18.078
3.000	0.943	1.526	17.834
3.100	0.967	1.616	17.605
3.200	0.989	1.707	17.391
3.300	1.010	1.797	17.190
3.400	1.030	1.889	17.000
3.500	1.049	1.980	16.822
3.600	1.067	2.072	16.653
3.700	1.084	2.163	16.494
3.800	1.101	2.256	16.342
3.900	1.116	2.348	16.199
4.000	1.131	2.440	16.063

CORE USAGE	OBJECT CODE=	1942 BYTES	ARRAY AREA=	7040 BYTES
COMPILE TIME=	0.14 SEC.	EXECUTION TIME=	0.11 SEC.	WATFIV - VERSION

Table A-14. Combine reel analysis, based on zero horizontal velocity of reel bar at entry criterion. Determination of relative magnitudes of Phases I, II, III.^a

Reel index	Phase I %	Phase II %	Phase III %	Contact index %
1.0	0.0	0.0	100.0	0.0
1.5	21.4	5.1	63.5	26.5
2.0	49.5	15.9	34.6	65.4

^aThe reel bar locus is illustrated in Figure 104 at a reel index $\lambda = 2.0$, for clarity. The reel axis is vertically above the tip of the cutterbar. The stalks are assumed to be straight and initially erect.

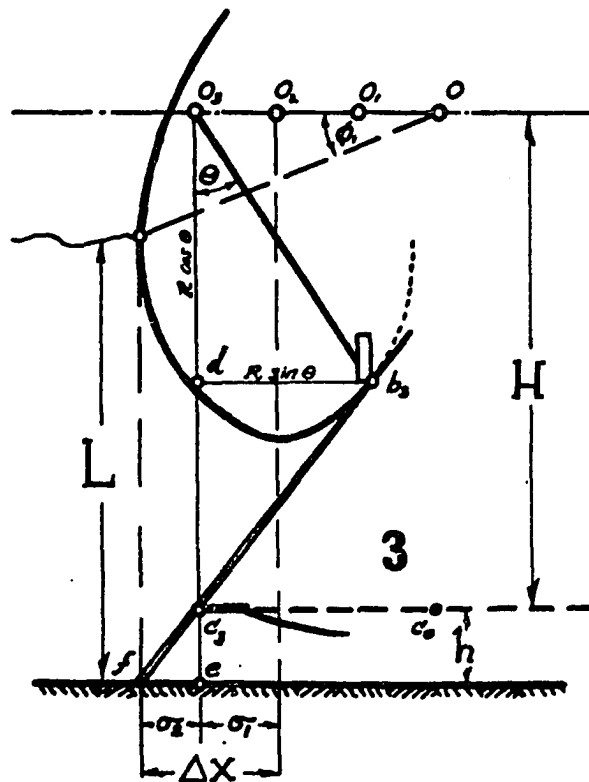


Figure 104. Reel geometry, showing Phases I and II.

Referring to Figure 104, when the reel bar first enters the crop, the cutterbar is at position C_0 . Theoretically, cutting of straight stalks being impressed by the reel cannot occur until C_3 , when the reel center is at O_3 .

Time taken for reel to move through angle θ is $t = \frac{\theta}{\omega}$ and for Phase I:

$$\sigma_1 = V t = V \frac{\theta}{\omega} = \frac{R}{\lambda} \theta$$

For Phase II:

$$\sigma_2 = \Delta x - \sigma_1 = \Delta x - \frac{R}{\lambda} \theta$$

Referring to similar triangles C_3b_3d and C_3ef :

$$\frac{\sigma_2}{R \sin \theta} = \frac{h}{H-R \cos \theta} \quad \frac{x - \frac{R}{\lambda} \theta}{R \sin \theta} = \frac{h}{H - R \cos \theta}$$

Figure 104 shows the cycloid for a reel index of 2.0, normally (i.e. at lower reel index values) angle θ is quite small and the following approximations are useful:

$$\theta \simeq \sin \theta ; \cos \theta \simeq 1.0$$

then
$$\frac{\Delta x - \frac{R}{\lambda} \theta}{R \theta} = \frac{h}{H - R}$$

Previously it was shown that

$$\Delta x = \frac{R}{\lambda} \left(\phi_1 - \frac{\pi}{2} + \sqrt{\lambda^2 - 1} \right)$$

$$\theta = \frac{(H-R) \left(\phi_1 - \frac{\pi}{2} + \sqrt{\lambda^2 - 1} \right)}{\lambda h + (H-R)}$$

and

$$\sigma_1 = \frac{R}{\lambda} \theta \quad \text{and} \quad \eta_1 = \frac{n \sigma_1}{X_\lambda}$$

Phase I

$$\sigma_3 = X_\lambda - (\sigma_1 + \sigma_2), \text{ and } \eta_3 = \frac{\sigma_3}{X_\lambda} \quad \text{Phase III}$$

At a cutting height $h = 4$ in., crop height $L = 36$ in., $R = 21.25$ in. and reel index $\lambda = 1.50$, the values in the table were obtained. When the reel is moved ahead of the cutterbar, contact index is enhanced, but only as Phase I is increased, Phases II and III remain unaltered.

$$X_1 = X_1 + K$$

$$\eta_1 = \frac{X_1 + K}{X}$$

If the reel is moved further forward than distance X , then the first reel bar loses influence over the plants, but the second reel bar begins to come into play.

Table A-15. Influence of reel index on header losses.^a Header lab test data with pickup reel in variety Amsoy, data averaged for two moisture levels, 9.3% and 14.5% MC. Rate of advance 2.5 mph, cutting height 4 in. Pickup reel tines set 5.5 in. above knife and 14 in. ahead.

Reel index λ	Average header losses, percent			
	Shatter	Stalk	Stubble	Total
0.72	6.0	27.0	6.2	39.2
0.74	9.3	18.3	5.0	32.6
0.90	4.8	5.1	5.2	15.1
0.95	3.3	5.5	3.2	12.0
1.00	3.0	4.4	4.0	11.4
1.10	3.1	2.9	2.9	8.9
1.10	3.2	3.9	2.5	9.6
1.20	3.4	3.4	2.8	9.6
1.25	3.4	3.1	2.5	9.0
1.30	2.4	3.1	2.9	8.4
1.35	2.8	3.0	2.1	7.9
1.40	2.0	3.0	3.0	8.0
1.50	3.4	2.8	2.5	8.7
1.60	3.0	3.1	3.0	9.1
1.70	3.8	2.8	3.2	9.8
1.90	4.0	2.3	3.6	9.9
2.10	4.6	2.0	3.4	10.0
2.50	4.1	3.4	3.4	10.9
2.90	5.3	5.1	3.3	13.7

^aRegression equations, data plotted in Figure 56:

$$\text{Shutter loss: } \hat{\pi}_{1,1} = \frac{2.6952}{2} + 0.5790 \lambda^2, S_{\pi_{1,1}/\lambda} = 1.0807\%$$

$$\text{Stalk loss: } \hat{\pi}_{1,2} = \frac{5.7151}{2} + 0.1368 \lambda^2, S_{\pi_{1,2}/\lambda} = 3.8791\%$$

$$\text{Stubble loss: } \hat{\pi}_{1,4} = \frac{2.5680}{2} + 1.0248 \lambda, S_{\pi_{1,4}/\lambda} = 0.7850$$

$$\text{Total } \hat{\pi}_1 = \frac{13.3761}{2} + 1.3115 \lambda^2, S_{\pi_1/\lambda} = 1.2404\%$$

Table A-16. Influence of reel index on header losses^a in 30% lodged Amsoys at 11% MC, 1971 field trial. Average combine speed 1.9 mph.

EXPT INPUT DATA

21.7800 2560.0000 8.0000 100.0000 343.0000

HEADER LOSS DATA EXPRESSED AS PERCENTAGES

PLOT IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STURBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE	STBL HT IN.
	$\pi_{1,1}$	$\pi_{1,2}$	$\pi_{1,3}$	$\pi_{1,4}$	π_1		
100 λ							
98	2.4477	6.1672	1.5268	1.3472	11.4890	2609.56	5.10
133	5.0836	10.5071	0.9175	0.7991	17.3073	2639.59	4.50
206	3.6675	7.7976	1.4381	0.9268	13.8300	2444.65	3.70
243	3.5279	11.5085	4.4366	1.9681	21.4412	2342.02	4.40
99	4.4570	7.7765	0.2807	1.2914	13.8056	2782.84	4.20
137	3.8038	12.5291	1.5589	0.9815	18.8733	2706.20	4.60
160	5.0092	11.5390	0.4111	1.5623	18.5216	2850.39	4.30
226	7.2556	14.6456	2.8211	2.1608	26.8831	2603.17	4.30
94	3.3747	12.6806	0.3663	1.1835	17.6052	2772.44	4.00
129	3.4512	13.0103	2.2847	1.3645	20.1108	2461.98	3.90
163	3.5930	16.9866	1.1211	1.0532	22.7538	2299.61	4.20
234	4.7967	14.6219	2.1017	0.4504	21.9707	2602.04	3.90
154	4.1871	13.4976	2.9092	1.4939	22.0878	2980.85	5.00
99	3.5590	12.4396	1.2895	0.1517	17.4398	3089.92	4.70
146	4.5966	13.7822	2.9705	2.1409	23.4902	2919.30	5.30
153	3.9146	12.2294	2.7485	1.8529	20.7455	2529.77	5.10
312	6.0525	9.8776	3.0135	0.5692	19.5128	2333.24	4.00
294	6.7076	6.6326	0.4077	1.4679	15.2158	2874.06	4.50

^aLeast-squares regression of total header loss on reel index λ :

$$\begin{aligned}\hat{\pi}_1 &= 9.7087 + 4.9703\lambda, \\ S_{\pi_1/\lambda} &= 4.6224\%.\end{aligned}$$

Table A-17. 1970 field test on Lynch and standard headers at three reel indices^a (same test as in Table 23, data plotted in Figure 61).

	Reel index	Average header losses, percent				Av. stubble length, in.
		Shatter	Stalk	Lodged and stubble	Total	
Standard	0.76	2.00	10.01	2.86	14.87	6.75
	1.12	2.78	3.89	1.25	7.93	5.90
	2.55	2.51	6.51	1.31	10.33	6.25
Lynch	0.84	1.73	2.65	1.15	5.53	5.85
	2.55	2.49	3.96	0.37	6.82	5.40
	3.81	2.54	4.18	1.15	7.87	5.85
Conclusions (Reel index overall means)		n.s.d.	*	n.s.d.	Diff. sig. at 10% level	n.s.d.

^aReel index for the Lynch was determined on the basis of an 18 in. drum diameter. The unit was mounted rigidly on platform with drum centers 6 in. from tip of cutterbar and 3 in. above cutterbar.

Table A-18. Header loss characteristics in three soybean varieties. Field^a, header lab test^b and Instron pod shatter test^c data compared.

A. FIELD TEST, 1970. 19.3% MC. Case 600 standard header, 2.5 mph

Variety	Average header losses, percent				Av. stubble length, in.
	Shatter	Stalk	Stubble	Total	
Standard					
Amsoy	1.34	3.91	1.22	6.47	6.18
Hawkeye	0.34	2.61	1.12	4.07	6.18
Corsoy	0.99	2.77	0.86	4.63	5.85
Lynch					
Amsoy	0.88	1.77	0.74	3.40	5.50
Hawkeye	0.87	2.66	2.43	5.96	6.42
Corsoy	0.94	2.85	1.73	5.52	5.50
Conclusions (Field tests on varieties, AOCV)				Diff. sig. at 10% level	n.s.d. (AOV)
n.s.d.				**	

B. HEADER LAB TEST, 1970. 13.5% MC; 2.5 mph, 4 in. cutting height

Amsoy	3.27	3.40	1.95	8.62
Hawkeye	3.52	3.44	2.58	9.54
Corsoy	2.33	4.10	3.20	9.63

C. INSTRON TESTS, 9% MC, 1 cm/min loading rate

	Mean peak pod compressive shatter force, lb.	Mean peak tensile shatter resistance, lb.
Amsoy	1.053	1.716
Hawkeye	1.811	2.324
Corsoy	1.205	1.916
Conclusions	**	**

^aSame test as described in Table 25. Field experimental layout similar to that illustrated in Figure 105.

^bHeader test stand with pickup reel and same reel settings as field test: reel tines 5-1/2 in. above and 14 in. ahead of knife, reel index 1.25, zero tine pitch.

^cNo significant difference detected between loading of pods on stem end or on peg end in compression tests.

DATE _____ RECORDER _____

COMBINE HEADER FIELD TRIAL LAYOUT

4 REPS X 2 DIRECTIONS X 3 SPEEDS X 2 CUTTERBARS (PAIRED: CN 960 COMBINE)

DIRECTIONS: 1 due East SPEEDS: 1 _____ CUTTERBARS: 1 Continuous Belt
 2 due West 2 _____ 2 Recip. Std.
 3 _____

REEL INDEX 1.5 NOM. CUTTING HEIGHT 4"

REPLICATE NO. IV	4	← 21	1 C	-----	REPLICATE NO. II	3	→ 13	2 R	-----
			2 R	-----				1 C	-----
	1	→ 11	2 R	-----		1	→ 11	2 R	-----
			1 C	-----				1 C	-----
	6	← 23	1 C	-----		6	← 23	1 C	-----
			2 R	-----				2 R	-----
REPLICATE NO. I	5	← 22	1 C	-----	4	← 21	1 C	-----	
			2 R	-----			2 R	-----	
	3	→ 13	2 R	-----	5	← 22	1 C	-----	
			1 C	-----			2 R	-----	
	2	→ 12	2 R	-----	2	→ 12	2 R	-----	
			1 C	-----			1 C	-----	
REPLICATE NO. I	3	→ 13	2 R	-----	REPLICATE NO. III	5	← 22	1 C	-----
			1 C	-----				2 R	-----
	4	← 21	1 C	-----		2	→ 12	2 R	-----
			2 R	-----				1 C	-----
	6	← 23	1 C	-----		4	← 21	1 C	-----
			2 R	-----				2 R	-----
REPLICATE NO. I	1	→ 11	2 R	-----	1	→ 11	2 R	-----	
			1 C	-----			1 C	-----	
	2	→ 12	2 R	-----	6	← 23	1 C	-----	
			1 C	-----			2 R	-----	
	5	← 22	1 C	-----	3	→ 13	2 R	-----	
			2 R	-----			1 C	-----	

ACCESS ROADWAY (9ROWS PER PLOT)

Figure 105. Typical field experimental layout, overseer's data recording sheet.

Table A-19. 1971 Comparison^a between Case 600 standard header and Case 960 with 10 in. extended rigid platform^b in Amsoys at 12.3% MC.

Header	Average header losses, percent					Stubble length, in.
	Shatter	Stalk	Lodged	Stubble	Total	
Standard	3.92	10.53	3.99	2.99	21.43	4.23
Extended platform	4.03	8.32	1.74	0.60	14.70	4.98
Conclusions: (AOCV)	n.s.d.	n.s.d.	diff. sig.at 10% level	**	n.s.d.	** (AOV)

^aTwo-way analysis of variance on trial means. Treatments: headers (2), directions (2) with four replications and four sub-samples per plot. Effect of direction of travel on total header loss not significant (at the 10% level), but direction x header interaction highly significant on shatter loss, stubble loss and stubble length.

^bReel settings: reel index 1.50; +10° reel tine pitch; reel tines 4 in. above cutterbar and 17 in. ahead on standard header, 7 in. ahead on 10 in. extended platform.

Table A-20. Influence of auger speed on header losses^a, header lab test in variety Amsoy at 11.25% MC.

Auger RPM	Average header losses, percent			
	Shatter	Stalk	Stubble	Total
97	5.5	2.4	2.1	10.0
120	7.5	4.5	0.9	12.9
121	4.4	3.4	2.2	9.2
155	4.3	3.7	2.2	10.2
170	5.5	2.1	1.7	9.1
170	6.0	1.1	1.2	8.3
170	7.3	2.3	2.3	11.9
170	4.3	1.2	0.9	6.4
238	4.8	2.2	1.2	8.2

^aLeast-squares regression fitting for a second degree polynomial showed no significant linear or quadratic coefficients (at the 10% level).

Table A-21. Influence of blade^a speed on cutting force and cutting energy. Severance of 3/16 in. maple wood dowels in Instron TBM and lab cutting analyzer^b. See Figure 69.

Blade speed fpm	Counter-edge cutting Force lb.	Impact cutting	
		Force lb.	Energy in. lb.
0.016	181.1	62.0	11.2
0.033	212.3	61.0	12.1
0.065	-	59.4	-
0.16	169.1	57.9	13.4
0.33	-	63.5	11.7
0.65	-	61.6	12.3
1.60	-	49.5	11.0
565.4	46.2	-	-
1130.8	30.5	-	-
4880.0	-	50.6	-
7470.0	-	37.5	-
9760.0	-	45.5	-

^aMedium sharp blade, 0.25 mm tip radius, 20° blade bevel angle.

^bFigures cited for lab cutting analyzer are averages for ten runs. Forces measured were peaks from chart records from Visicorder and are subject to the limitations mentioned in section 8.1.1.

Table A-22. Cutting comparisons between soybean stems and 3/16 in. diameter maplewood dowel. Representative peak force and total energy values, INSTRON tests^a with medium sharp blade.

Treatment	Counter-edge		Simulated impact	
	Force lb.	Energy in.lb.	Force lb.	Energy in.lb.
3/16 in. dowel	212.3	27.2	61.0	12.1
0.22 in. soybean stem	49.5	3.2	30.5	3.6
0.33 in. soybean stem	92.8	16.4	53.3	8.1

^aINSTRON TTBM, loading rate 1 cm/min, simulated impact tests conducted on stems at 9% MC and sticks glued into clamping blocks spaced to provide a two in. span fixed-ended beam.

Table A-23. Some representative soybean stem properties, pertinent to a study of the impact cutting phenomenon. Variety Amsoy, typically 0.22 in. diameter between nodes, 9% MC.

Quantity	Magnitude
Stem mean distributed weight, stems and pods, w lb./in. stem only, w' lb./in.	0.00105 0.00035
Stem stock SG	0.387
Mean modulus of elasticity ^a , psi	423,000
Flexural rigidity, EI_a average ₂ for cantilever and built-in beam tests ^a , lb.in. ²	44
Mass moment of inertia about CG, 3l in. stem piece, including pods ^b , lb.sec ² .in.	0.0052
Estimated flexural wave propagating velocity ^c , fps	1333
Estimated time for flexural wave to propagate to ground, if cutting at 4 in. height, sec.	2.5×10^{-4}
Estimated time for severance by single impact cut, sec.	2 to 4×10^{-4}
Estimated mean peak cutting force, single impact cut at 7500 fpm, F_{max} lb.	10 to 20
Estimated maximum stem-piece velocity at severed end, after single impact cut at 7,500 fpm blade speed, V fpm	5735
Estimated stem rotational velocity after severance, rad/sec	$5.4 V/60 L$

^aDetermined from 2% tensile strain values on prepared stem tensile test specimens loaded at 1 cm/min rate on Instron TTBM testing machine, Serial number 2135.

^bFound from average oscillation times for stems individually suspended as a simple pendulum: $I_G = Wl_o[(\tau^2/4\pi^2) - (l_o/G)]$ where W = stem weight, lb.; l_o = distance from pivot to CG, in.; τ = mean period of single oscillation, sec.

^cBased on the assumption of a sinusoidal flexural waveform of wavelength $\lambda = 2$ in.; substituting in the wave equation (21): Wave velocity = $4\pi/\lambda \sqrt{EI_G/w}$, in./sec.

The following additional data and observations were collected in an unsuccessful bid to predict, by theoretical analyses, stem cutting and pod shattering behavior, refer to Figures 106 and 107.

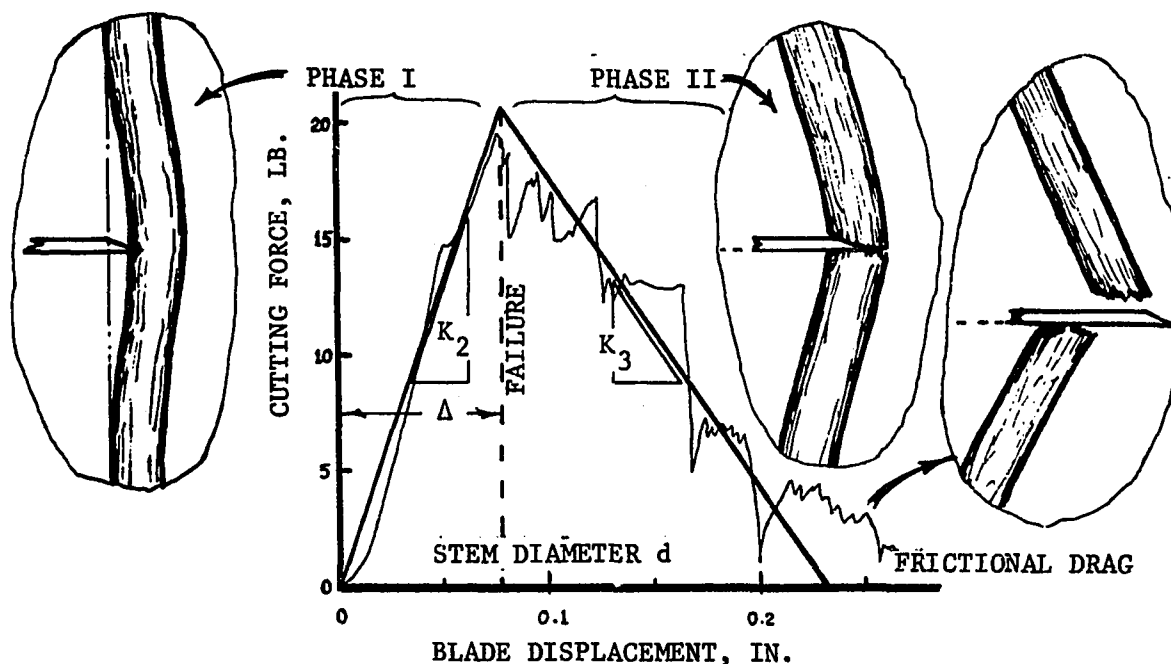


Figure 106. Impact cutting hypothesized, using information from INSTRON stem cutting tests (see Figure 73).

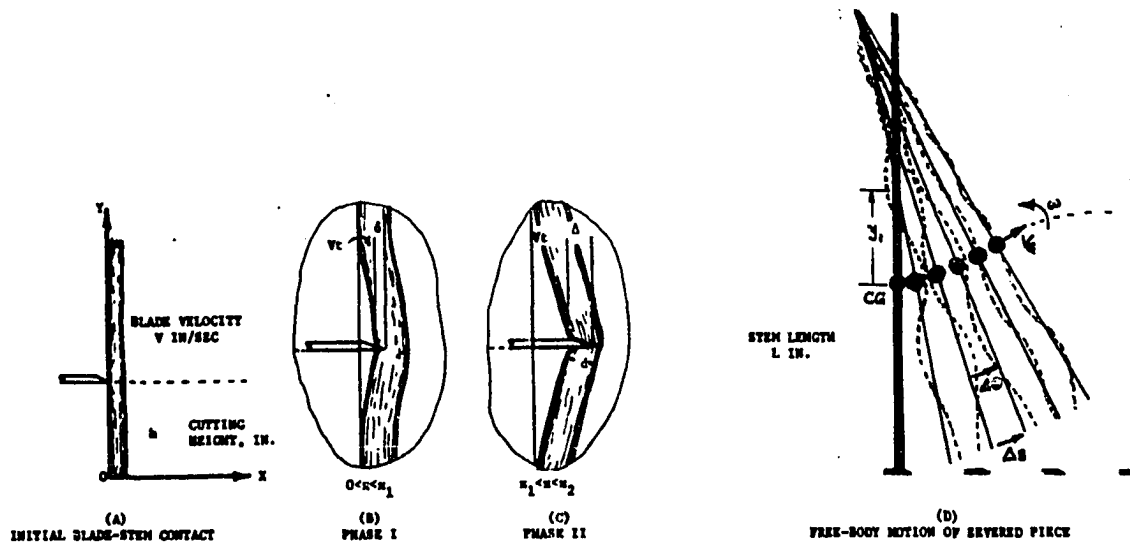
Assumptions used in analysis:

That the forward speed of the combine is small as compared with lateral speed of the blade.

The problem is resolved into an analysis of motion in the X-Y plane only, considering stem element to be severed before the flexural wave extends beyond the bounds of the system. Thus there are no external forces on the system, Figure 107B.

As the blade encountered the stem in Phase I of the cut, stem bending and indentation are assumed elastic. Bending stiffness = K_1 lb./in. (found from analogy with built-in beam model); local deformation stiffness = K_2 lb./in.

After blade has penetrated to a depth Δ into stem (at time t_1) the fibers on the far side of the stem fail. The blade proceeds through the stem against a constantly diminishing resistance and frictional drag.



Phase I $IF_0 = ma$ for stem system in the inertial reference frame XY

$$k_2 s - k_1 x = m \frac{d^2 s}{dt^2}, \quad \text{and } s = Vt - x \quad k_1 = \frac{192 EI}{L^3}$$

$$\frac{d^2 x}{dt^2} + \left(\frac{k_1 + k_2}{m} \right) x = \frac{k_2 V}{m} t.$$

Let $\omega_1^2 = \frac{k_1 + k_2}{m}$

General Solution is $x = \frac{k_2 V}{k_1 + k_2} \left[t - \frac{1}{\omega_1} \sin \omega_1 t \right]$ [Developed from the works of Konstantinov (36) and Semenov (70)]

when $s = \Delta$, $\frac{ds}{dt} = V_1$ and $t = t_1$, where $\Delta = Vt_1 - x_1$

Phase II $IF_0 = ma$ for stem system (C)

$$F_{max} - k_3 x = m \frac{d^2 x}{dt^2}, \quad \text{and with } \omega_2^2 = \frac{k_3}{m}$$

$$\frac{d^2 x}{dt^2} + \omega_2^2 x = \frac{F_{max}}{m}$$

General Solution is $x = \beta \sin(\omega_2 t + \alpha) + \frac{F_{max}}{m \omega_2^2}$

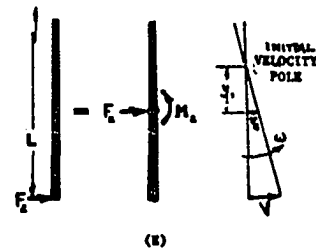
where β & α are found from the initial conditions: $\left. \frac{dx}{dt} \right|_{t=t_1} = V_1$, $x|_{t=t_1} = x_1$

thus $\beta^2 = \left(x_1 - \frac{F_{max}}{k_3} \right)^2 + \left(\frac{V_1}{\omega_2} \right)^2$ and $\tan \alpha = \frac{\omega_2}{V_1} x - \frac{F_{max}}{m \omega_2^2}$

At time t_2 , when the blade has penetrated completely through the stem,

$$d = V(t_2 + t_1) - x_2$$

Values of k_1 , k_2 and k_3 could not be determined for an actual impact cut, but, using the Instron Simulation, the following values were found: $k_1 = 960$; $k_2 = 333$; $k_3 = 150$ lb/in, and for a stem diameter of 0.22 in., the predicted stem displacements x_1 and x_2 and times t_1 and t_2 were found to be several times larger than those estimated from film at a blade speed of 7,500 fpm. A probable source of error could lie in the assumption of a fixed system boundary and constant mass m in the above analysis.



It can be shown¹, for a stem subject to an eccentric impact, the velocity pole for the free stem is located at the center of percussion

$$\text{i.e. } y_1 = \frac{L}{6}$$

$$\text{and } m = \frac{6V}{L}$$

From the movie of the blade severing stem LSP 2 at 7,500 fpm, the coefficient was found from

$$\frac{C'}{L} = \frac{ds/dt}{ds/dt} = \frac{dv}{ds}$$

$$C'_{av} = 5.4$$

¹ Mischke, C.R. I.S.U. Linear Impulse. Personal Communication. Sept. 13, 1971.

Figure 107. An analysis of single impact stem cutting.

Table A-24. Summary of results^a of counter-edge and impact cutting of soybean stems on the lab cutting analyzer. Data plotted in Figure 75.

1. COUNTER-EDGE CUTTING. Single blade on disc					
Medium sharp blade Amsoy 7.7% MC ^b		Dull blade Amsoy 9.2% MC		Medium sharp blade Amsoy 9.2% MC	
Blade speed fpm	Shatter %	Blade speed fpm	Shatter %	Blade speed fpm	Shatter %
422	0.0	422	0.0	422	0.0
558	3.66	545	0.0	545	0.0
613	-	613	0.0	613	0.0
715	-	681	9.45	681	0.66
844	3.60	715	-	715	3.86
1,125	28.50	953	11.00	817	9.26
1,270	14.66	1,230	-	1,230	11.85
1,630	28.90	1,360	17.20	1,360	11.71
1,690	29.81	1,690	14.50	1,630	16.29
2,040	-	2,040	21.11	2,040	14.80
3,380	35.68	2,720	12.60	2,720	14.93
4,220	38.80	4,090	28.10	4,090	20.23

2. IMPACT CUTTING. Two medium sharp blades mounted on disc					
Amsoy 7.7 % MC		Hawkeye 8.0% MC		Amsoy 9.2% MC	
Blade speed fpm	Shatter %	Blade speed fpm	Shatter %	Blade speed fpm	Shatter %
2,990	49.80	3,410	41.38	3,410	-
3,750	39.33	4,090	48.37	4,090	28.72
4,770	-	4,770	38.92	4,770	-
5,580	39.80	5,450	46.41	5,450	27.73
6,130	-	6,130	48.69	6,130	-
6,810	-	6,810	42.67	6,810	23.70
7,490	41.50	7,490	35.23	7,490	20.29
8,170	-	8,170	41.19	8,170	20.30
9,180	38.15	8,850	36.75	8,850	20.76
9,530	-	9,530	28.09	9,530	7.82
10,220	-	10,220	13.29	10,400	7.16
11,900	9.32	10,900	26.62	11,900	3.89
14,030	9.20	11,580	21.09	12,000	5.01
14,300	10.45	13,620	17.95	13,000	4.61
15,000	14.60	15,000	-	15,000	12.65

^aEach data point represents average of at least five stems cut. Av. stem diameter 0.22 in. at the point of cut (4-1/2 in. from clamp).

^bMoisture content referred to is average stem MC (oven moisture determinations).

Table A-25. Influence of cutterbar speed on header losses^a. Header lab test in variety Amsoy at 7% MC. Rate of advance 2.5 mph.

Cutterbar speed, N rpm	Advance ratio, π_3	Average header losses, percent			
		Shatter	Stalk	Stubble	Total
190	0.396	4.71	2.60	4.40	11.71
195	0.406	5.32	1.23	0.74	7.29
200	0.421	5.53	1.82	1.75	9.10
250	0.526	4.70	0.51	0.38	5.59
260	0.541	2.58	0.51	1.42	4.51
300	0.625	3.08	0.61	0.45	4.14
340	0.708	1.98	0.56	1.00	3.54
360	0.750	2.54	0.83	0.60	3.97
400	0.833	3.11	0.49	0.41	4.01
450	0.937	2.67	0.60	1.07	4.34
500	1.041	3.11	0.61	0.71	4.43
560	1.166	4.00	0.34	1.00	5.34
600	1.249	4.20	0.26	0.80	5.26
660	1.374	4.45	0.27	0.70	5.43
700	1.457	5.90	0.30	0.60	6.80
710	1.478	4.45	0.52	0.52	5.49
720	1.499	4.84	0.26	0.52	5.62
780	1.624	4.51	0.63	0.76	5.90

^aLeast-squares regression equations:

$$\text{Shatter loss } \hat{\pi}_{1,1} = \frac{1.3812 \times 10^5}{N^2} + 9.1650 \times 10^{-6} N^2, S_{\pi_{1,1}/N} = 1.4493\%$$

$$\text{Stalk loss } \hat{\pi}_{1,2} = \frac{3.1786 \times 10^4}{N^2} + 0.3532, S_{\pi_{1,2}/N} = 0.9999\%$$

$$\text{Stubble loss } \hat{\pi}_{1,4} = \frac{2.1909 \times 10^2}{N} + 0.2608, S_{\pi_{1,4}/N} = 1.2457\%$$

$$\text{Total } \hat{\pi}_1 = \frac{2.7735 \times 10^5}{N^2} + 1.1404 \times 10^{-5} N^2, S_{\pi_1/N} = 0.9247\%.$$

Table A-26. 1968 field comparison of reciprocating cutterbars. Results analyzed and summarized in Table 30.

EXPT INPUT DATA 8.7120 2530.0000 20.0000 30.0000 871.20							
HEADER LOSS DATA EXPRESSED AS PERCENTAGES							
PLOT ^a IDENT	SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE	STBL HT IN.
1111	3.7801	6.6304	0.0000	0.0000	10.4105	2712.37	4.50
1112	3.6671	13.6329	0.0000	0.1532	17.4532	2580.36	4.00
1113	2.4632	3.5764	0.0000	0.8453	6.8849	3039.25	4.00
1114	1.2131	6.7844	0.0000	0.0000	7.9975	2912.96	4.00
2121	4.4863	22.3211	0.0000	0.1577	26.9651	2505.65	4.00
2122	0.9986	1.4731	0.0000	0.2326	2.7044	2548.93	4.00
2123	2.4840	5.1699	0.0000	0.0000	7.6539	3172.85	3.50
2124	3.6691	5.2227	0.0000	0.6620	9.5538	2686.68	4.00
3131	4.2043	6.1590	0.0000	0.2431	10.6065	2438.66	5.00
3132	3.4951	18.7014	0.0000	1.6888	23.8852	3159.70	5.00
3133	3.3675	9.4949	0.0000	1.5473	14.4098	2809.90	3.50
3134	4.3417	6.0465	0.0000	0.8111	11.1993	2680.16	4.00
4211	1.3180	12.3564	0.0000	0.4887	14.1630	2830.95	4.50
4212	2.1613	8.4689	0.0000	1.5398	12.1700	2823.64	4.50
4213	2.4485	9.2340	0.0000	0.5213	12.2038	2653.87	4.00
4214	0.8171	5.5022	0.0000	0.4127	6.7320	2873.44	3.50
5221	3.7296	11.8929	0.0000	0.8155	16.4381	2908.02	4.00
5222	3.8901	8.3539	0.0000	2.1581	14.4021	2838.85	4.50
5223	1.6627	5.0870	0.0000	0.2180	6.9677	2719.49	4.00
5224	2.8473	8.7062	0.0000	1.0447	12.5982	2837.47	4.00
6231	5.3321	12.4877	0.0000	0.1505	17.9702	2627.09	4.00
6232	2.0561	18.9099	0.0000	0.5327	21.4987	2968.10	5.50
6233	3.8916	6.6409	0.0000	0.0000	10.5324	2380.75	4.00
6234	3.1965	17.3393	0.0000	0.6282	21.1640	3145.77	4.00
7311	6.2421	4.1430	0.0000	1.1630	11.5481	2718.99	4.00
7312	1.5691	7.2432	0.0000	0.2869	9.0992	2755.75	4.00
7313	1.4042	6.9269	0.0000	0.4708	8.8018	2938.66	4.00
7314	2.3100	3.9344	0.0000	2.0374	8.2818	2812.96	4.30
8321	3.7453	14.1710	0.0000	0.0647	17.9810	3054.17	4.00
8322	2.3559	10.8338	0.0000	0.2626	13.4523	3009.90	4.00
8323	1.6183	12.3072	0.0000	0.0000	13.9255	2794.09	3.50
8324	1.3802	13.8774	0.0000	0.0000	15.2576	3133.02	4.00
9331	4.1104	10.0526	0.0000	0.0000	14.1630	2830.95	4.00
9332	3.2453	11.0096	0.0000	0.1251	14.3800	3159.31	3.50
9333	2.5978	14.4703	0.0000	0.3429	17.4110	2881.74	4.00
9334	1.8502	7.4352	0.0000	1.0009	10.2862	2764.35	4.00

^aIdentification: First digit=plot number; second digit=replication; third digit=location within block; fourth digit=cutterbar: 1=3x3(standard), 2=3x1-1/2, 3=1-1/2x3, 4=1-1/2x1-1/2.

Table A-27. 1969 Field comparison between the standard reciprocating cutterbar and a 1-1/2 in. x 1-1/2 in. special cutterbar.

EXPT INPUT DATA

8.7120 2590.0000 40.0000 20.0000 217.8000

HEADER LOSS DATA EXPRESSED AS PERCENTAGES

PLOT IDENT	^a SHATTER LOSS	STALK LOSS	LODGED LOSS	STUBBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD LB/ACRE	STBL HT IN.
2111	0.0000	1.1088	0.0000	1.2474	2.3563	2785.64	4.00
2212	0.0176	1.5678	0.0000	2.2577	3.8431	3078.30	3.50
2221	0.6124	6.6120	0.0000	4.5272	11.7515	3240.85	5.80
2122	4.2936	9.6511	0.0000	7.4409	21.3856	2620.39	7.50
2211	0.0905	3.5343	0.0000	1.9085	5.5332	2731.12	3.50
2112	1.5357	4.9567	0.0000	1.0752	7.6077	3052.20	3.50
2221	2.0170	7.5608	0.0000	7.5608	17.1386	3089.50	7.00
2222	1.9152	9.6927	0.0000	6.8505	18.4585	2648.96	7.50
1122	2.4844	4.7108	0.0000	12.4656	19.6608	2663.71	7.00
1121	3.6454	8.9447	0.0000	3.8156	16.4056	3086.33	6.50
1221	1.6760	3.7609	0.0000	3.7611	9.1980	3085.73	6.70
1222	2.0423	4.1187	0.0000	7.6935	13.8545	2484.17	7.00
1211	2.3284	7.2365	0.0000	0.6362	10.2010	2427.64	3.70
1111	0.0000	1.3154	0.0000	0.7399	2.0552	2348.26	3.70
1212	0.0000	2.2201	0.0000	0.2018	2.4220	2869.50	3.90
1112	1.3930	6.0692	0.0000	5.7079	13.1701	2671.89	4.30
4211	0.3437	4.8167	0.0000	1.1065	6.2669	2965.87	3.50
4222	1.2888	1.8775	0.0000	6.4804	9.6468	3187.49	6.50
4111	0.6525	3.4910	0.0000	0.5078	4.6513	3041.47	3.90
4121	3.9716	6.8370	0.0000	8.1285	18.9371	2541.23	8.00
4212	0.3495	3.6409	0.0000	2.0522	6.0426	2916.22	3.50
4122	3.3783	4.1132	0.0000	0.8912	8.3827	2816.06	7.00
4112	1.0865	3.2709	0.0000	1.3510	5.7084	2714.98	4.00
4221	3.8203	5.3638	0.0000	2.8309	12.0150	2591.35	6.80
3122	1.3472	6.3772	0.0000	4.1850	11.9094	2906.10	7.50
3222	0.3102	5.0731	0.0000	3.7686	9.1518	2663.78	7.20
3112	0.3092	3.3951	0.0000	0.5056	4.2099	2672.51	3.50
3111	1.2163	3.1272	0.0000	0.5323	4.8757	2901.47	3.80
3212	0.0899	2.3868	0.0000	0.0702	2.5468	2750.04	3.20
3221	2.7192	6.1610	0.0000	2.9075	11.7877	2788.73	7.60
3121	1.6673	8.0771	0.0000	9.0204	18.7647	3274.44	7.20
3211	0.3997	5.6777	0.0000	5.2992	11.3766	2550.12	4.20

^aFirst digit = block number; second digit - cutterbar: 1 = 3x3 (standard), 2 = 1-1/2x1-1/2; third digit = stubble length: 1 = 3-1/2 in., 2 = 7 in.; fourth digit = combine speed: 1 = 2.0 mph, 2 = 2.9 mph.

Table A-28. 1967 Field test comparison between standard header and Love floating cutterbar at 2.5 mph. Variety Amsoy, 13% MC. Data summarized in Table 32 and also plotted in Figure 92.

IDENT ^a	HEADER LOSS %	STUBBLE LENGTH in.	IDENT	HEADER LOSS %	STUBBLE LENGTH in.
10101	20.71	5.5	30101	9.98	4.5
10102	21.75	5.3	30102	12.16	4.5
10103	13.85	4.0	30103	13.53	4.0
10104	19.13	4.5	30104	10.97	4.0
10105	17.74	4.5	30105	17.38	4.5
10106	21.10	3.5	30106	10.48	4.0
10107	22.31	5.3	30107	10.55	5.0
10108	18.15	4.5	30108	9.55	4.5
10109	23.55	5.0	30109	10.21	5.0
10110	17.74	4.5	30110	13.07	5.0
10201	7.65	3.0	30201	5.76	3.0
10202	6.81	2.9	30202	8.01	3.3
10203	11.49	3.0	30203	7.13	3.1
10204	11.28	4.5	30204	9.12	3.4
10205	9.93	3.5	30205	8.67	3.5
10206	11.49	3.6	30206	4.64	3.0
10207	13.22	2.5	30207	9.59	3.5
10208	8.44	2.5	30208	4.76	3.5
10209	8.87	2.5	30209	14.51	5.0
10210	6.41	2.5	30210	5.54	3.0
20101	16.02	4.0	40101	11.02	4.1
20102	12.89	4.5	40102	10.62	4.0
20103	13.72	3.5	40103	11.13	4.0
20104	17.62	4.0	40104	9.57	4.5
20105	15.82	4.0	40105	10.69	4.5
20106	17.98	4.5	40106	8.41	4.0
20107	15.70	4.5	40107	9.79	4.5
20108	19.32	3.5	40108	7.23	4.0
20109	12.45	3.5	40109	9.07	4.0
20110	16.27	4.5	40110	6.26	3.5
20201	5.57	2.5	40201	7.03	3.2
20202	8.41	2.5	40202	10.94	3.5
20203	7.25	3.5	40203	6.85	2.0
20204	7.29	2.5	40204	5.97	3.2
20205	10.23	2.5	40205	7.17	3.0
20206	6.59	2.5	40206	10.43	4.0
20207	12.53	2.5	40207	6.76	3.0
20208	10.23	2.5	40208	10.56	5.5
20209	9.20	2.5	40209	5.40	3.0
20210	7.94	4.5	40210	10.64	5.5

^aIdentification: Column 1 = block number, see Figure 103; Column 3 = Headers (1 = standard, 2 = Lovebar); Columns 4 and 5 = subsample no.

Table A-29. Merit figures for selection of cutterbar design.

DESIGN ALTERNATIVE (Fixed Platform Cutterbars)	SUBJECTIVE PERFORMANCE, ACCEPTABILITY & FEASIBILITY FACTORS						FIGURE OF MERIT = $\frac{f_1 \times f_2 \times f_6}{f_3 \times f_4 \times f_5}$
	f_1 DURABILITY & RUGGEDNESS	f_2 CAPACITY	f_3 STUBBLE LENGTH	f_4 HEADER LOSS or SHATTER	f_5 COST	f_6 SPECIAL COMMENTS	
CONVENTIONAL RECIPRO- CATING 3" CUTTERBAR (The Standard of Com- parison)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BALANCED HEAD RECIPRO- CATING 3" CUTTERBAR (Not tested)	1.4	1.5	0.9	1.1	1.4	1.0	1.51
TWIN or DOUBLE-KNIFE RECIPROCATING CUTTERBAR (Model tested)	0.9	2.0	0.8	0.8	1.7	1.0	1.66
CONTINUOUS CHAIN CUTTERBAR (Chain saw type - model tested)	0.8	2.2	0.6	1.7	1.3	(Wear & soil build up on 0.8 guards)	1.06
BAND SAW (Shop model tested) (requires bulky end pulleys)	1.2	0.4	0.4	0.5	0.6	0.5 (soil accu- mulation on guards and pulleys)	2.00
THE LASER (Several stems tested)	10.0	1.0	0.3	0.1	100.0	(Operation 0.2 hazard - fire risk)	0.66
HELICAL ROTARY SICKLE (Lab-tested by Bledsoe [5])	1.5	3.0	1.4	1.7	0.7	(Platform obstruction 0.5 to stalks)	1.35
THE MACHETE (Fully tested in 1971)	0.7	8.0	0.4	2.0	1.4	0.9 (limited in width)	4.50

Table A-30. 1971 Field comparison between the Machete and the standard reciprocating cutterbars, Figure 105. Results analyzed and summarized in Table 33.

PLOT IDENT	a SHATTER LOSS	STALK LOSS	LODGED LOSS	STURBLE LOSS	TOTAL HDR LOSS	NET POTL YIELD	STBL HT
1111	6.5785	4.4292	0.5051	0.7771	12.2899	2409.94	3.10
1112	2.2659	7.8094	0.3497	0.0389	10.4638	2409.94	4.50
1121	6.5266	5.0328	2.2838	0.2115	14.0546	2213.94	3.00
1122	4.4120	9.4735	1.0996	0.5075	15.4926	2213.94	4.30
1131	8.5028	4.2667	2.3804	0.9432	16.0929	2084.80	3.90
1132	6.1224	5.5242	0.9432	2.2456	14.8354	2084.80	6.70
1211	6.7046	3.1492	0.5905	0.1181	10.5623	2378.62	3.20
1212	4.8544	8.3453	0.2362	1.6533	15.0892	2378.62	3.90
1221	10.2048	11.9601	2.8216	0.3369	25.3233	2223.38	4.30
1222	4.2248	19.6246	2.7373	1.6845	28.2713	2223.38	6.80
1231	10.5474	7.4303	1.0351	0.2588	19.2715	2532.90	3.80
1232	6.8507	10.2768	1.4787	0.8502	19.4563	2532.90	4.20
2111	11.9263	6.7228	2.2409	0.1494	21.0395	2506.96	5.10
2112	4.7553	5.0048	1.3819	1.5687	12.7106	2506.96	4.80
2121	10.0792	9.2242	2.2058	0.1604	21.6696	2334.68	5.40
2122	3.8629	2.1256	4.5720	0.8021	11.3626	2334.68	5.60
2131	12.6791	8.0264	1.9620	0.0992	22.7557	2099.82	7.60
2132	7.3272	6.9562	0.2230	0.8026	15.3090	2099.82	9.50
2211	9.7726	7.1089	0.1205	0.0000	17.0020	2331.30	3.70
2212	4.5915	5.9442	0.4418	0.3615	11.3389	2331.30	4.20
2221	8.9820	5.3604	1.4221	0.3646	16.1292	2567.75	5.60
2222	2.5278	6.5637	0.8752	1.8962	11.8628	2567.75	5.30
2231	6.7377	6.4774	1.2517	0.0939	14.5606	2992.26	4.90
2232	2.7324	6.2583	5.3822	1.9714	16.3443	2992.26	5.30
3111	9.1617	4.6682	2.2154	0.0747	16.2201	2507.18	3.40
3112	4.2320	8.5896	1.5312	0.7096	15.0623	2507.18	5.40
3121	8.3459	4.6840	1.4465	0.0000	14.4765	2718.61	4.00
3122	4.7295	11.2968	0.7233	0.2066	16.9562	2718.61	5.70
3131	13.2939	8.3902	4.0957	0.0398	25.8196	2354.71	3.40
3132	8.4825	15.2694	1.9882	1.3917	27.1318	2354.71	5.40
3211	11.7103	7.8667	0.8649	0.0824	20.5243	2273.36	4.90
3212	5.0792	23.3530	2.2653	1.0297	31.7272	2273.36	5.50
3221	6.5735	8.3951	0.4997	0.0999	15.5683	2810.62	3.90
3222	4.4081	8.4284	0.4997	0.6663	14.0025	2810.62	4.40
3231	9.9539	9.0116	1.0103	0.0000	19.9757	2317.04	4.50
3232	3.7711	11.5170	4.4452	1.8993	21.6326	2317.04	7.70
4111	13.4663	5.9076	3.8495	0.6098	23.8331	2456.69	4.60
4112	4.6620	7.2797	1.8294	1.5245	15.2957	2456.69	4.60
4121	11.2215	5.3560	3.4049	0.8417	20.8240	2447.47	4.40
4122	4.4118	7.1158	1.7981	1.4920	14.8177	2447.47	4.80
4131	5.7293	2.5857	0.5099	0.4370	9.2618	2571.06	4.80
4132	2.7066	6.3367	3.0955	1.1654	13.3042	2571.06	5.40
4211	8.4416	6.3315	0.7001	0.0000	15.4732	3075.99	2.80
4212	5.0932	4.7182	0.7306	1.4002	11.9422	3075.99	3.40
4221	10.8958	5.5686	0.2976	0.2551	17.0170	2202.69	3.80
4222	4.7745	6.0362	0.0850	2.0829	12.9787	2202.69	4.50
4231	8.0185	8.0448	1.3537	0.7349	18.1519	2420.89	3.70
4232	3.7254	4.0611	0.5028	0.5415	8.8307	2420.89	4.20
FXPT INPUT DATA		17.4240	2670.0000	10.0000	20.0000	210.0000	

^aIdentification: First digit = block number; second digit = direction of travel; third digit = combine speed: 1 = 1.6 mph, 2 = 2.7 mph, 3 = 3.2 mph; fourth digit = cutterbar: 1 = Machete, 2 = standard.

Table A-31. Influence of combine forward speed on header loss and stubble length, Machete vs. standard reciprocating cutterbars. Prediction equations and results shown in Figures 99 and 100.

Combine speed		Total header loss, percent		Stubble length, in.	
fpm	mph	measured	predicted	measured	predicted
<u>A. Machete continuous belt impact cutterbar</u>					
102	1.16	11.5123	14.9940	3.0000	3.6698
138	1.57	17.1180	15.3224	3.8900	3.7491
165	1.88	19.7130	15.5735	4.1900	3.7983
197	2.24	9.2407	15.8764	—	—
238	2.70	18.1328	16.2731	4.3500	3.9767
270	3.14	17.7624	16.5896	4.6500	4.0690
281	3.19	18.2362	16.6998	4.5800	4.0796
446	5.07	23.1569	18.4436	4.6100	4.5000
450	5.11	22.3964	18.4880	3.5300	4.5094
514	5.84	17.0200	19.2142	3.8200	4.6844
660	7.50	29.4819	20.9792	4.9500	5.1080
700	7.95	20.2268	21.4904	5.2800	5.2293
732	8.33	17.2911	21.9084	6.3700	5.3340
845	9.60	20.2525	23.4504	5.6800	5.6993
<u>B. Standard reciprocating cutterbar</u>					
102	1.16	7.2331	10.6033	3.5000	3.9118
138	1.57	15.4537	11.8651	4.5800	4.2581
165	1.88	22.5394	12.9090	4.9100	4.4841
197	2.24	9.5844	14.2658	—	—
238	2.70	15.7180	16.2146	5.2200	5.3796
270	3.14	19.2290	17.9189	5.6800	5.8923
281	3.19	17.1055	18.5452	6.0400	5.9536

Table A-32. Influence of moisture content on header losses, Machete vs. standard reciprocating cutterbars, 1971 field trial in 30% lodged Amsoys. Results shown in Figure 101.

Moisture content MC %	Header losses, percent	
	Measured	Predicted
<u>A. Machete: total header loss</u>		
12.8	18.50	19.2766
13.2	18.00	17.9011
14.5	15.30	13.4306
15.5	8.80	9.9917
<u>B. Machete: shatter loss only</u>		
12.8	9.10	7.6063
13.2	5.20	6.8876
14.5	4.40	4.5515
15.5	3.10	2.7546
<u>C. Standard cutterbar, total header loss</u>		
12.8	16.70	17.7161
13.2	17.10	16.5441
14.5	14.20	12.7349
15.5	8.80	9.8048
<u>D. Standard cutterbar, shatter loss only</u>		
12.8	3.90	3.0497
13.2	1.80	2.7248
14.5	1.50	1.6689
15.5	1.10	0.8567